STS Science Education

Unifying the Goals of Science Education
1990

Curriculum Support

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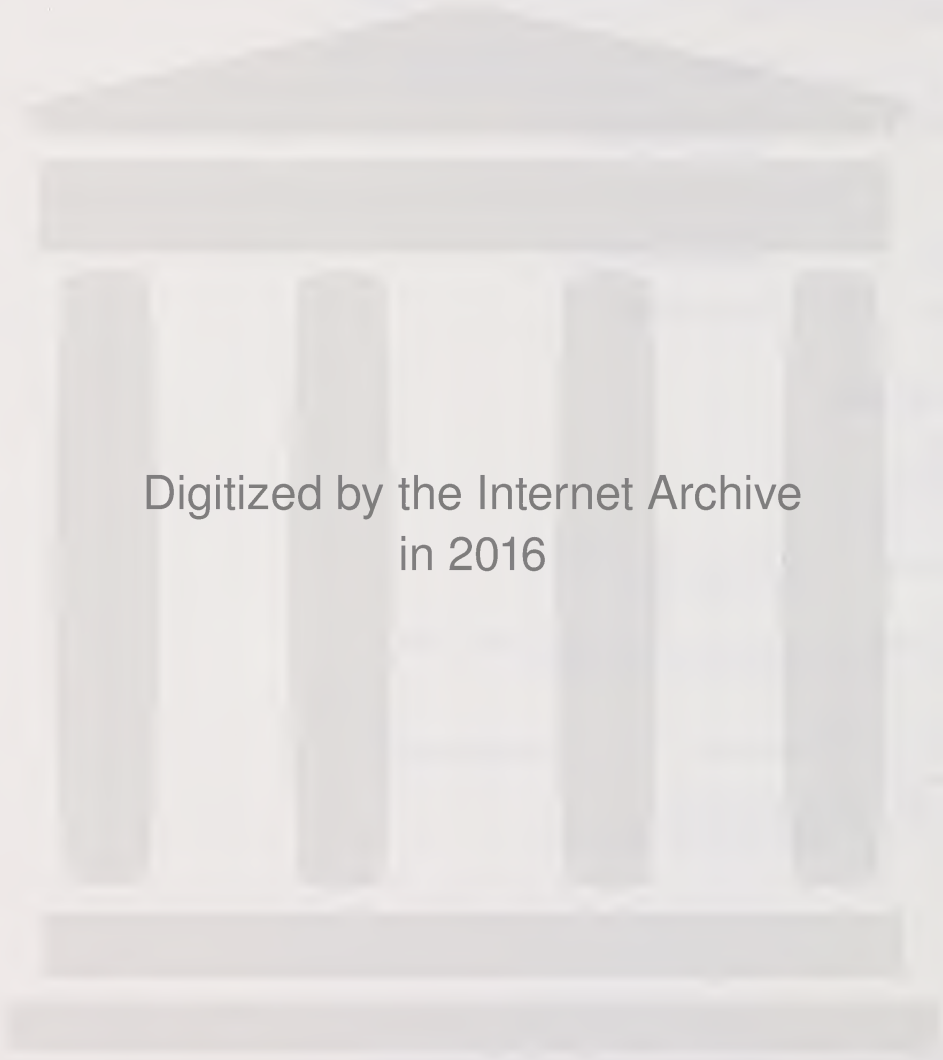
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Foreword

The first steps in the development of this monograph were taken when the need for an explanation and description of STS (Science, Technology and Society) science education was recognized. The STS acronym has become the buzz phrase in science education across North America and internationally. STS is an important concept and heralds the first significant change in science education in 25 years. With that in mind, Alberta Education prepared this monograph. Designed as a support document for Alberta Education's new science programs, it provides a comprehensive description that will help teachers integrate the STS concept into their teaching schemes. Science educators throughout the school system will find this monograph useful in explaining and describing the basis of an all new science education.

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STS Science Education: Unifying the Goals of Science Education

Throughout the Western World the 1980s were a time of reflection on the goals of science education. After a four-year study of Canadian science education the Science Council of Canada (1984) recommended that, "science should be taught at all levels of school with an emphasis and focus on the relationship of science, technology and society (STS) in order to increase the scientific literacy of all citizens." This monograph, **STS Science Education: Unifying the Goals of Science Education,** provides a comprehensive description of the STS movement in science education. The STS approach strives to broaden the scope of science education by integrating into the science program accurate presentations of the nature of science, the nature of technology and the interactions of science and technology with each other and with society. The STS approach is intended to serve the needs of students who will continue to study and work in the sciences, as well as the total population of students who will be the citizens of the 21st century.

STS is an international science education movement. The STS concept has become a useful rubric for unifying, organizing and describing diverse policy and goal statements. Australia, Great Britain, the United States, Canada and other countries are involved in STS curriculum development. STS is being championed not only by traditional science educators and teachers but also by scientists, engineers, social scientists and politicians. For example, the American Chemical Society has sponsored the writing of an STS chemistry textbook, **ChemCom** (Chemistry in the Community); the British Teachers' Association for Science Education has sponsored the **SaTiS** (Science and Technology in Society) Project; **NASTS** (National Association of Science, Technology and Society) has been established along with an STS Network and an annual STS conference in the United States; in the state of Victoria, Australia, the new curriculum and state-wide tests for the academic sciences have a strong STS orientation; the provinces of Ontario, Saskatchewan, Alberta and British Columbia have committed themselves to using STS concepts to design science curricula; Alberta universities have been offering STS courses and are now in the process of organizing interdisciplinary programs leading to a bachelor's degree in Science, Technology and Society; and, internationally, there is a Science and Technology Research Network (STS–RN) and an annual international conference for university science education researchers.

> *"Science education of the past has not helped prepare citizens for the life they will live. It has focused entirely upon preparing people for careers they will not follow. Fortunately there are many encouraging signs on the horizon; fortunately there are many examples of 'new programs' that have been designed to respond to the current situation."*
>
> *Robert E. Yager (1983: 53)*

What is it about the STS concept that has captured the attention of people interested in science education? STS can accommodate a wide variety of science education interest groups, those interested in hard science as well as those interested in the nature of science, science and technology and STS issues. The primary motivation to make STS an important part of science curricula is the realization that the effects of science and technology on society must be understood by the citizens of society. As Alberta Education's **Secondary Education in Alberta Policy Statement** (1985) states, the best preparation for students to anticipate and shape the future is a broad general education with emphasis on critical and creative thinking, communication, personal development, science and technology and an understanding of the community.

All educators would agree that students should be exposed to as broad a science education as is necessary to be successful citizens. All students, including future scientists, engineers and technicians, are citizens. But not all students will become scientists, engineers or technicians. What is certain is that all citizens will have to make more and more decisions on STS issues. Therefore, not only will our citizens and leaders have to be more scientifically and technologically literate, but they will have to be more aware of the limitations of science and technology in solving problems in our society. For example, many people have come to believe that scientists and technologists will always be able to provide a "technological fix" for environmental problems created by the needs and wants of modern lifestyles. If citizens are expected to make judicious decisions on increasingly complex issues, then as students they must gain some understanding of how to make those decisions with an understanding of science, technology and society.

The time has come for curriculum and textbook developers to provide leadership in systematically unifying diverse forms of knowledge. Typically, in the past, curriculum goals have been diverse and curriculum objectives, materials and instruction, narrow. The least expert person on the education hierarchy—the student—has ironically been expected to integrate diverse knowledge forms. The other person expected to do the integration is the teacher. The challenge issued by Alberta Education's **Review of Secondary Programs** (1985) is to make everyone responsible for the achievement of all the goals of science education. To fulfil the dream of a science education with a unified set of goals, a clear blueprint is required.

Advantages of the STS Concept

Many people see the STS concept as a means to provide more balance in setting and achieving the objectives for science education. For years science educators have drawn a wide variety of objectives from the general goals of education, including statements that go beyond the standard conceptual and descriptive knowledge found in science curricula. However, the objectives achieved and tested for science education have generally been narrowly restricted to scientific concepts and descriptions. Most science educators are now seeking to broaden the objectives that will be both achieved and tested. The "science" part of STS has been broadened to include not only scientific knowledge (i.e., concepts and descriptions) but also scientific process skills, attitudes and knowledge of the nature of science. This horizontal expansion of the objectives for science curricula is accompanied by a vertical expansion into the realms of technology and society. (See Figure 1.) The responsibility of curriculum designers and teachers will be to decide how extensively to present knowledge, skills and attitudes in the study of technology, society and of STS interactions.

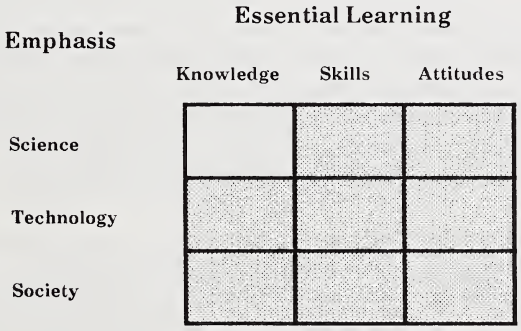

Figure 1. Standard Science Content and Expanded STS Content

The range of goals for science education to be unified and integrated by STS is wide. The Science Council of Canada study, and the Second International Science Study of the International Association for the Evaluation of Educational Achievement (Connelly et al. 1985), found that the goals for secondary school science in Alberta in the 1970s and 1980s were very similar to the goals stated for science education across Canada.

For purposes of this monograph it is useful to define standard science content as scientific knowledge (i.e., scientific concepts and descriptions) and to define extended STS content as science, technology and society knowledge, skills and attitudes beyond the standard science content.

Objectives for Secondary School Science

1. To promote an understanding of the role that science has had in the development of societies. [Society]
2. To promote an awareness of the humanistic implications of science. [Society]
3. To develop a critical understanding of those current social problems that have a significant [science] component. [Society]
4. To promote understanding of and development of skill in the method used by scientists. [Science]
5. To promote assimilation of scientific knowledge; e.g., fundamental ideas and practical applications of science, the open-endedness of science and the tentativeness of scientific knowledge. [Science and Technology]
6. To develop attitudes, interests, values, appreciations and adjustments similar to those exhibited by scientists at work. [Science]
7. To contribute to the development of vocational knowledge and skill. [Technology]

(Program of Studies for Senior High Schools, Alberta Education 1976)

These goals are not new but they can all be classified within the new science, technology and society categories. The advantage of the STS model is that the number of general categories of objectives is reduced and their classification is simplified. As well, the knowledge, skills and attitudes components apply to each of the three STS categories.

Educators must then decide which of, and to what extent, the knowledge, skill and attitude components of science, technology and society will be covered in a curriculum. This is not only the decision of the curriculum and textbook designer but of the teacher in the classroom as well. Although the program of studies sets out the components of the curriculum, the teacher must be aware of opportunities to integrate extended STS components in the day-to-day activities of the classroom. This integration of STS components is the main challenge to teachers presenting a curriculum that tries to meet all the objectives of science education.

Kinds of STS Courses

Secondary school STS courses range from those that have limited science content (such as the British **SISCON**— Science in a Social Context—course and the British Columbia Science and Technology materials), to those with some science content (the American **ChemCom** and the Saskatchewan **LoRST**—Logical Reasoning in Science and Technology—materials), to the British **SaTiS** materials, the Australian State of Victoria curriculum and Alberta's new science curriculum, all with extensive science content. Within this continuum, as the standard science content increases , there is usually a corresponding decrease in the extended STS content. (These course materials are described in the "Sample STS Textbooks" section of the bibliography, p. 55.)

The differences among STS courses go beyond the degree to which they include STS content and standard scientific concepts and descriptions. The scientific content, the technological and societal content, and the STS interactions also vary from one STS course to another. For example, STS programs of study may focus on scientific process skills, STS issues, science and technology interactions, or some other combination of STS components. The grade level of the student can also determine the selection of STS components; e.g., junior high school students may concentrate on scientific process skills while high school students may extend this to a broader study of the nature of science. Similarly, a general science course may emphasize STS issues to a greater extent than a science discipline course which in turn may emphasize the nature of scientific knowledge to a greater extent.

Even though the amount of scientific content varies in STS courses, the amount of standard scientific content found in an STS science course is generally a high percentage of the total content of the course. For example, science courses in Alberta secondary schools have traditionally contained a high percentage of scientific knowledge; i.e., concepts and descriptions. However, over the years, the actual program of studies in Alberta's classrooms has evolved to include a greater emphasis on process skills and technological applications. In the proposed programs of studies for science, traditional curricular emphases continue to be prominent. The scientific process skills and problem-solving components have been broadened to include technological and societal skills, problem solving and a greater emphasis on the nature of science. The technology component has been broadened from technological

applications to include a study of science and technology interactions; e.g., case studies of technology leading science and of science leading technology.

The newest addition to the curriculum is the handling of STS issues. Technology, and indirectly science, has had an increasing effect on society and has produced results that are perceived as mainly positive. However, STS issues such as those arising from chemical warfare, genetic engineering, the greenhouse effect, abortion and cruise missiles, are increasing in number. The extent to which these issues are dealt with in programs of study generally increases from a discipline science course such as physics to a general science course in high school or junior high to a liberal arts STS course at university. An STS **science** course is not a social studies or philosophy course; it is a science course first and an STS course second. However, the kind and extent of science, technology and society content are variables that can be manipulated from one program of studies to the next.

Often people are of the belief that STS means a program that is driven by STS issues. Although programs that focus on STS issues are appropriate in certain contexts, this kind of program represents only one of the kinds of STS programs that can be designed. Theoretically, an STS program could, for example, focus on scientific process skills, technological applications, science and technology interactions, and/or the nature of science. However, a balanced STS program would not restrict itself to just one of these STS components. Although it might be appropriate in certain applications to emphasize one of the STS components more than another, careful thought should be given to the kind and extent of each STS component in each program of studies.

Curriculum Emphases

The classification of science curricula content as topics of study (e.g., atomic theory, electricity, ecology) and as essential learning (e.g., knowledge, skills and attitudes) has been used in science education for many years. Topics of study and essential learning are, themselves, concepts created by science educators to organize and present scientific knowledge. To use Kaplan's words, "concepts mark the paths by which we move through logical space" (1964). Recently, science educators have added two new concepts to help us steer a path toward a more unified and balanced science curriculum—a curriculum that meets all the objectives of science education. These two new concepts are STS science education (see Bybee 1986) and curriculum emphases (see Roberts 1982).

STS is a concept that enables us to integrate science, technology and society components in any course (but especially a science course) in a logical and consistent way. The STS concept can be used to make decisions about the quantity of technological and societal knowledge that should appear in a science course—or for that matter, the quantity of science and technology in a social studies course.

Curriculum emphases, when combined with the STS concept, allow for the systematic introduction of scientific, technological and societal knowledge to science courses. When Roberts (1982) developed and then applied the concept of curriculum emphases, he indicated that not all goals can be met to the same extent in all units of study. For example, if the nature of science, the interdependence of science and technology, and decision making on STS issues are to be introduced into the curriculum, then each of these objectives might be emphasized in different units of study in a textbook. By matching each topic or unit of study to a particular curriculum emphasis, the nature of science or STS issues can be covered more systematically and extensively than otherwise possible. The alternative is a more shallow and less systematic presentation of important concepts such as the nature of science.

> *"A curriculum emphasis is a coherent set of messages about science. ... Such messages can be communicated both implicitly and explicitly. A curriculum emphasis [can] be made to materialize in five or six weeks (although not much less than that). ... The coherence and flow [of curriculum emphases] are matters of concern as much as the coherence and flow of the subject matter itself."*
>
> *Douglas Roberts (1982: 245, 250, 251)*

The STS and curriculum emphases concepts are both products of the 1980s. Developed independently, they have now merged in Canada. Several curriculum projects and provincial departments of education have united the concepts, suggesting that the emphases of curricula being developed should be science, technology and society. There are, of course, variations in the topics selected for curriculum emphasis. For example, some curricular groups declare their curriculum

emphases to be the nature of science, the interaction of science and technology, and decision making on STS issues. Whatever the topic chosen, the concept of curriculum emphases can be used to clarify and describe what we believe to be an acceptable curriculum for the 1990s and into the 21st century.

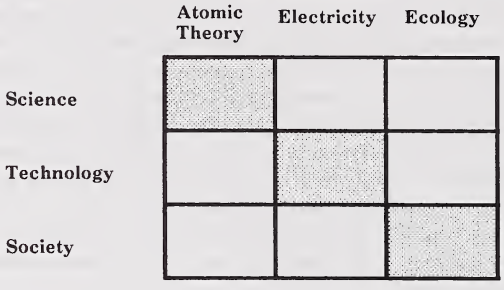

Figure 2. Matching STS Curriculum Emphases With Topics of Study

In Figure 3, science, technology and society curriculum emphases have been matched to particular units of study. Although, theoretically, every unit of study in a science curriculum can be written to emphasize certain program goals , there usually seems to be a curriculum emphasis that most naturally fits particular units of study. For example, atomic theory and acid-base theory may more readily allow for the integration of ideas about the nature of science than for ideas about STS issues. Electricity seems to fit a technology emphasis easily, and the topic of ecology seems most suited to a discussion of STS issues. The matching of units of study with an emphasis on one or a few related curriculum objectives is not always easy, but the strategy of using curriculum emphases to meet curriculum goals seems to be a logical and systematic approach to meeting all the goals of science education.

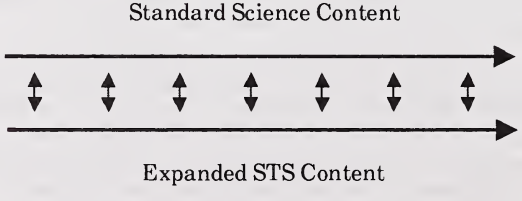

Figure 3. Parallel Streams of Standard Science and Expanded STS Content

For a science curriculum, standard scientific knowledge will continue to dominate the content of the unit of study; the amount of STS content will vary depending on the overall objectives of the course. Curriculum emphases are used to indicate which goals (as implicit and explicit messages) should be emphasized in a unit of study, but this does not exclude other goals from being met. For example, lower level technology objectives such as technological applications may be addressed in a unit on atomic theory that has a nature of science emphasis. The topic of electricity might include an emphasis on technology but might also meet learner expectations on scientific skills and on the effect of technology on society. In short, a curriculum emphasis does not exclude other kinds of goals from being met. It does allow for a more focused effort to meet a particular goal in a particular unit of study. The aim of this strategy is to systematically meet all of the goals set out for science education. Although there are usually more than three goals expressed in policy statements for science education, these goals can, for simplicity, be categorized in three classes—science, technology and society.

Science Curriculum Emphasis

If a three-dimensional model for describing curriculum were used, curriculum emphases would be on one dimension, essential learning (KSA) on the second dimension and topics of study on the third. In this model, each curriculum emphasis would intersect with the essential learning components—knowledge, skills and attitudes. (See Figure 4.) To describe STS science education in this monograph, curriculum emphases have been classified under science, technology and society.

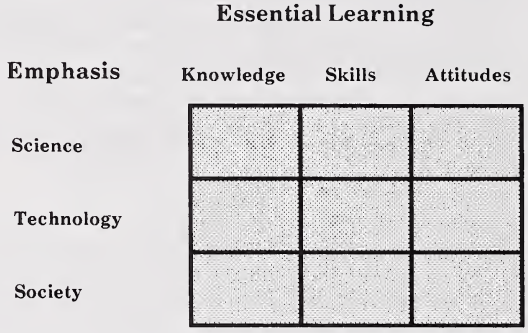

Figure 4. Intersection of Essential Learning and Curriculum Emphases

The goals of education and the specific objectives of science education, can be addressed within each of the STS curriculum emphases. For example, a science curriculum might have any or all of the following components: 1) scientific knowledge, 2) scientific process skills, 3) scientific attitudes and values, 4) scientific problem solving and 5) the nature of science. The depth and breadth of the curriculum emphasis would depend on the grade level and ability of the students. In elementary school, process skills such as making and communicating observations might be emphasized, while the teachers could demonstrate generally accepted scientific attitudes. In junior high school, medium-level scientific process skills such as application and analysis might be emphasized, with teacher-directed discussions to illustrate and highlight scientific attitudes and problem-solving skills. A science curriculum emphasis in junior high school would normally expect more independent work by the student and more modelling of the language of science by the junior high school teacher. In high school the initial skills and thought processes learned earlier would be reinforced and extended to include a greater emphasis on analysis, evaluation and synthesis. It would also seem appropriate for senior high school students to learn, from

teacher modelling and examples such as the differing concepts of theorists Francis Bacon, Karl Popper and Thomas Kuhn, several alternative interpretations of the nature of science. Ideally, therefore, a science curriculum emphasis should reflect a continuum from elementary through senior high school, ultimately on into postsecondary institutions.

If, as Roberts (1982) defines it, a curriculum emphasis must convey a coherent set of implicit and explicit messages about science, then the set of messages is going to be incomplete until the student has progressed through a science curriculum emphasis to the explicit treatment of the nature of science (see Component 5 below). A science curriculum emphasis involves parallel streams of knowledge, skills and attitudes that become more advanced as the intellectual maturity of the student advances. At any point in the student's science education, some combination of the following components of a science curriculum emphasis might be conveyed both implicitly and explicitly.

Just as an emphasis on one curriculum goal does not exclude the achievement of other goals, an emphasis on one component of a curriculum emphasis does not exclude the presentation of other components. The concepts of STS and curriculum emphases were created by those who value a broad and balanced science education.

Components of a Science Curriculum Emphasis

1. Scientific knowledge
2. Scientific process skills
3. Scientific attitudes
4. Scientific problem solving
5. Nature of science

1. Scientific Knowledge

Scientific knowledge includes the *concepts and descriptions* that scientists in the scientific community have developed to represent natural phenomena. Scientific concepts include theories, laws, generalizations and definitions; e.g., atomic theories, Newton's laws, generalizations concerning the appearance of Homo sapiens and an Arrhenius definition of acids. Descriptions can be direct or indirect. Direct descriptions come from observations of a phenomenon, while indirect descriptions are products of the application of a concept. For example, oxygen (under standard conditions), might be directly described as a colourless gas that supports combustion and respiration. According to Lewis' Molecular Theory, oxygen might be indirectly described as being composed of diatomic molecules with four lone-pairs of electrons and one double, non-polar-covalent bond. The direct description of oxygen is empirical (observable) while the indirect description is theoretical (non-observable).

Scientific concepts and definitions can also (like descriptions) be classified as empirical and theoretical. Scientific laws (e.g., Newton's Laws) are empirical while scientific theories (e.g., acid-base theories) are theoretical, that is, based on non-observable entities and processes. Definitions can be either

empirical (operational) or theoretical (conceptual). For example, empirically an acid is a substance that turns blue litmus red while theoretically an acid is a substance that ionizes in water to produce hydrogen ions. The classification of scientific knowledge as empirical and theoretical is not only useful for portraying the nature of scientific knowledge but can also be useful to teachers for organizing the presentation of scientific knowledge to students in a metacognitive sense. Nadeau and Désautels (1984) and American Association for the Advancement of Science (1989) call for teachers to reflect on the nature of scientific knowledge and to get students thinking about how scientific knowledge comes to be accepted by the scientific community.

Scientific knowledge will undoubtedly continue to be the main content of any science curriculum. Curricula are usually set in terms of scientific concepts rather than descriptions, but students are most often asked to use these concepts to produce descriptions. With these points in mind, it becomes evident that teachers (and students) must come to a broader understanding of the nature of scientific knowledge.

"Science as knowledge is an intellectual construct, and what are referred to as the laws of nature are merely the result of this human activity. Nature as such does not have laws, but its behaviour can be described and predicted on the basis of laws and theories formulated by scientists."

Nadeau and Désautels (1984: 19)

2. Scientific Process Skills

When scientific process skills are emphasized in a particular unit of study, students are then provided with activities that allow them to learn and practise these processes and skills. Normally, process skills are defined as being part of laboratory work or at least research work outside the usual classroom mode. The processes may include formulating a problem, devising an experimental design, making a prediction, writing a procedure, gathering evidence, analysing the evidence and evaluating the prediction, scientific concept (or hypothesis) and experimental design. The process skills include a variety of skills scientists use in scientific problem-solving situations. Scientific process skills most often taught in Alberta are listed in the **Science Process Skills** position paper (Galbraith 1983) prepared by the Alberta Education Science Curriculum Co-ordinating Committee.

Scientific Process Skills

1. **Questioning** (identifying questions and defining problems)
2. **Proposing ideas** (hypothesizing and predicting)
3. **Designing experiments** (identifying and controlling variables and determining procedures)
4. **Observing and measuring** (gathering evidence)
5. **Processing evidence** (classifying and organizing and displaying evidence)
6. **Interpreting evidence** (inferring and formulating models)

The intent of the **Science Process Skills** position paper was to review the several process skill inventories and to prepare a framework that could be used in elementary through high school to integrate the discrete skills approach with an holistic inquiry approach. The result is the inquiry-process model in Figure 5.

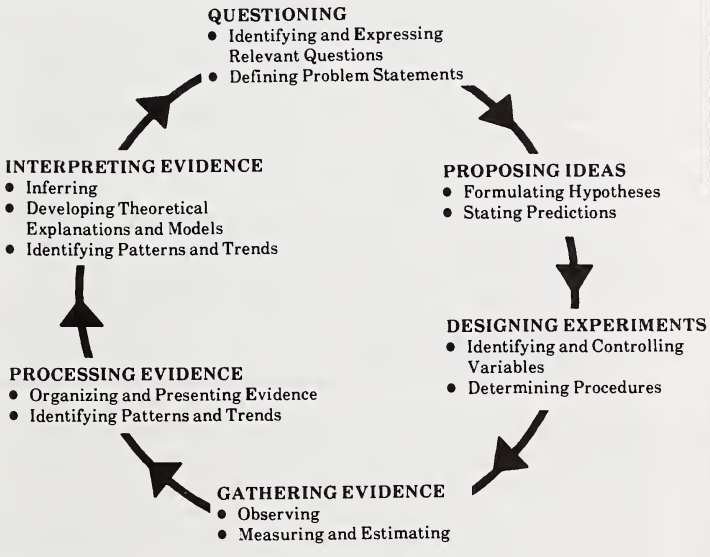

Figure 5. Inquiry-process Model

As with any model, this inquiry-process model is only a limited representation of the "real" inquiry process. The cyclic model used here is one step better than a linear model but is still too linear to describe an inquiry process.

Alberta has a rich tradition of emphasizing process skills in science courses.

A **scientific** *attitude is a general predisposition or mental set. Attitudes* **toward** *science are discussed in this monograph in the society curriculum emphasis section.*

3. Scientific Attitudes

The term "attitudes" has a specific definition in education. Alberta Education's **Essential Concepts, Skills and Attitudes** document defines attitudes as "a general predisposition or mental set." In science education Nay and Kozlow (1976) have compiled an inventory of scientific attitudes or predispositions that are or ought to be displayed by individuals doing scientific work.

Scientific Attitudes

1. **Critical-mindedness** (looks for consistency and challenges the validity of statements)
2. **Suspended judgment** (recognizes the restricted nature of evidence and scientific concepts)
3. **Respect for evidence** (looks for evidence through an empirical approach)
4. **Honesty** (reports all evidence and acknowledges the work of others)
5. **Objectivity** (considers pros and cons and all the evidence available)
6. **Willingness to change** (alters hypotheses, interpretations, inferences and concepts)
7. **Open-mindedness** (considers several possible alternatives when investigating a problem)
8. **Questioning attitudes** (asks many questions: how, who, where, when and why)

Other scientific attitudes include curiousity, appreciation for beauty and complexity, and confidence in personal ability. Some of these predispositions are general to many kinds of work (e.g., honesty) but some of them are quite specific to science (e.g., respect for evidence). Although some people seem to possess some of these predispositions naturally, most educators believe that it is important to foster scientific attitudes through laboratory work and classroom modelling and discussions.

4. Scientific Problem Solving

There are those who argue that the knowledge, skills and attitudes triad should be knowledge, problem solving and attitudes. Their argument is that scientific problem solving subsumes scientific processes, which in turn subsume scientific skills.

This monograph includes sections on scientific problem solving, technological problem solving and societal decision making. The three approaches to problem solving are somewhat different because their goals differ. Scientific problem solving seeks explanations for natural phenomena, technological problem solving strives to develop practical devices or processes and societal decision making is concerned with what should be done about a particular issue. Some educators advocate a generic problem-solving model based on the common elements of the different approaches.

The level of process skills must be progressively increased over the years of a student's science education. In elementary school teachers model skills for their students, but in junior high school the students should begin to use these skills with greater independence. The amount of teacher dependence should decrease with each year of science education. At higher grade levels, process skills necessary for scientific problem solving in and around the laboratory should emphasize higher cognitive processes, such as analysis, evaluation and synthesis, to a greater extent. These students should also be able to independently write problem statements, design experiments and procedures, and decide on the kind of evidence needed to answer the problem.

Over the years the students should come to an understanding of the purpose of scientific work. For example, they should realize that the purpose of the work they are doing in the laboratory is to test the scientific concept (or their own hypothesis) that is used to make the prediction. An understanding of the interplay of the concept being tested with the prediction, the evidence and the experimental answer to the problem is crucial to the understanding of the nature of science and of the nature of scientific knowledge. Classroom experience indicates that students often confuse evidence with predictions or hypotheses with predictions. One explanation of student difficulties might be the level of abstraction required in the assignment. In general, students at all grade levels need to start with concrete experiences and then move (when appropriate) to abstract understanding. Another explanation of this problem lies in the lack of experience students have with scientific problem solving in the laboratory and with the lack of discussion about the purpose of scientific work. A discussion of the purpose of scientific work adds the nature of science as a component to a science curriculum emphasis.

5. Nature of Science

Teaching the nature of science is not just teaching about and applying the processes and skills associated with science or just developing scientific attitudes. It includes teaching the concepts that philosophers of science have developed to describe the nature of the scientific endeavour and the origins, limits and nature of scientific knowledge. Teaching the nature of science involves teaching the concepts (if not the skills and attitudes) that have come to be accepted as warranted knowledge by philosophers of science.

> *"A theory is a good theory if it satisfies two requirements: It must accurately describe a large class of observations on the basis of a [simple] model ..., and it must make definite predictions about the results of future observations."*
>
> *Stephen W. Hawking (1988: 9)*

Three commonly mentioned views of the nature of science are those of Francis Bacon (1600s), Karl Popper (1930s) and Thomas Kuhn (1960s). Bacon's concept of the scientific endeavour is most easily summarized as inductive reasoning. Simply, Bacon's inductive description suggests that science involves the synthesis of generalizations from systematic observations; i.e., specific to general reasoning. This view of science is still dominant in many of today's textbooks. As a simple view of science, Bacon's concept is still useful in the appropriate context, just as John Dalton's concept of the atom in 1805 is still useful in the appropriate situation. Basically, Bacon's concept is what is normally called the *scientific method.* The scientific method was appropriate for describing what science was (or was becoming) in Bacon's time. It is one approach that science students and scientists can use to begin a new area of study. By the process of induction, a foundation of concepts is built from experience and experiment.

The Popper concept of science expresses itself in the terms *verification, falsification* and *testing concepts.* A concept can be tested by making a prediction, gathering evidence to test the prediction and evaluating the prediction and concept. If the prediction is verified, then the scientific concept is judged to be acceptable. However, if there is even one instance of a prediction that is falsified (and the experiment is replicated by reputable scientists), then the concept is refuted and must be restricted, revised or replaced. The view of science presented by Popper is that the aim of science is to continually test and distrust its own knowledge. One way of becoming a famous scientist is to devise an experiment that will overthrow a currently accepted scientific concept. This is the reason many people believe that scientific knowledge is the most trustworthy knowledge available. However, there are other views of science of which both teachers and students should become aware during their science education.

"A concept of science drawn from [science textbooks] is no more likely to fit the enterprise [of science] that produced them than an image of a national culture drawn from a tourist brochure ..."

Thomas Kuhn (1970: 1)

Reading Thomas Kuhn's (1970) **The Structure of Scientific Revolutions** is not an easy task. However, Kuhn's concepts and descriptions of the nature of science are very important, as witnessed by the widespread acceptance of these ideas both inside and outside the scientific community. Despite the skepticism expressed by Kuhn in the margin quote, many science educators believe that it is possible to provide students with a more realistic view of the nature of science. The ideas that Kuhn suggested for describing the scientific endeavour more realistically are summarized below. These ideas were developed through Kuhn's thorough and meticulous research into the history of scientific thought.

The Ideas of Thomas Kuhn

1. Scientific ideas are accepted by the consensus of scholars in the scientific community and not always for reasons that can be described as being entirely rational (e.g., peer pressure and social context influence scientific acceptance of knowledge).
2. There are periods in the history of science where normal science or revolutionary science prevail. Long periods of normal science, which gather support for and increase the certainty of currently held concepts, are periodically followed by revolutionary science and a time of confusion when a new way of thinking about the world is required.
3. Knowledge products and processes, called *paradigms*, are employed by the scientific community to represent the body of knowledge that is communicated to young scholars in the field. This body of knowledge is usually well articulated and is communicated in science courses and textbooks.

The increasingly explicit presentation of the nature of science as grade levels progress provides students with a context for and an understanding of scientific work. If students can understand the underlying principles of scientific work, they will be much better prepared for understanding the role that science can play in our society, as well be able to see the limitations of science for solving our problems. The "don't worry, be happy" attitude that science and technology can solve all of our problems is reflected in the terms technological fix and scientific-technological fix. The discussion of this societal attitude and the problems that it causes can occur in either a unit of study with a nature of science emphasis or in one with an STS-issues emphasis, but it must be discussed in science classrooms. This discussion cannot and should not be left to social studies classrooms. It is only from within the context of a science course that students can truly come to appreciate and understand the nature of the scientific endeavour. A scientifically literate society must understand the interactions of science, technology and society and foster these interactions in an informed manner. An understanding of the nature of science and of the STS interactions requires a long-term, progressive and systematic integration of STS curriculum emphases in the science curriculum.

A secondary problem that stems from citizens and policy makers not knowing the nature of science and of technology and the differences between them is that the goals for technology become mixed with the goals for science. The result has been that funding for scientific work has increasingly been

> *"[Teachers] convey a concept of science at the very moment when they may think they are merely transmitting accepted knowledge... Epistemology is the analysis of accepted ideas about what is considered to be science, it can give those who are training scientific minds an opportunity of reflecting on the value and legitimacy of the image of science they are portraying."*
>
> *Nadeau and Désautels (1984: 12, 15)*

predicated on the economic and technological spinoffs that are anticipated. The Canadian scientific community has become increasingly frustrated by this definition of scientific work that is worthy of funding. Most recently, 1986 Nobel Laureate John Polanyi has tried to educate the public and policy makers about the utilitarian criteria imposed as conditions on the funding of scientific work. Although the idealistic scientific search for pure knowledge is an extreme point of view, the push by policy makers and those who allocate research funds is becoming increasingly utilitarian. The place of science education in this debate is to educate students about the nature of science, of technology and of the interaction of science and technology. Students must be aware of the tremendous impact of science and technology on society, but at the same time they must be aware of the roles and limitations of science and technology in STS problem solving.

6. Summary

A science curriculum emphasis is usually attached to a science content topic that includes a number of empirical and theoretical concepts. The relationship between, and evolution of, empirical and theoretical concepts must be easy to see and analyse in the selected topic area; e.g., periodic laws and atomic theories, the properties and theories of light, or heredity and DNA. In a science course there is a major emphasis on scientific conceptual and descriptive knowledge in every chapter or unit of study. Most of the remaining content in a unit with a science curriculum emphasis will be scientific process skills, scientific problem solving, scientific attitudes and values and/or the nature of science content. To a lesser extent all of these curricular components appear in all units of study, but when science is the curriculum emphasis, they are given greater emphasis. In a unit of study with a science curriculum emphasis, technological and societal knowledge may provide occasional contexts for questions but would likely constitute only a small proportion of the total content.

"When deliberating over a controversial decision, scientific and technical knowledge is more often misused than ignored. ... A thoughtful strategy for decision making would be to avoid such abuses of science. Abuses may arise, or go undetected, due to a lack of understanding the characteristics and limitations of science and technology."

Glen Aikenhead (1985: 463)

A science curriculum emphasis in a science course involves presenting one or more areas that depict the scientific endeavour (e.g., scientific problem solving and the nature of science) in parallel with the standard knowledge, skills and attitudes that normally appear in a unit of study. A curriculum emphasis is not meant to get in the way of teaching the standard content; a curriculum emphasis provides a systematic way of handling the multiplicity of goals and objectives that are often listed but not realized in a program of studies. Just as the standard concepts and descriptions are handled systematically through a scope and sequence approach, the extended STS curricular objectives can be handled systematically through the use of parallel curriculum emphases tied to each unit of study.

Technology Curriculum Emphasis

The concept of a technology curriculum emphasis in a science course must be justified. One could ask why technology should be included in, for example, a physics or a biology course presented by "science" teachers in a "science" department. On the other side of the argument, some educators say that physics and biology should be the primary classifications, not science; science and technology are both secondary classes. (See Figure 6.)

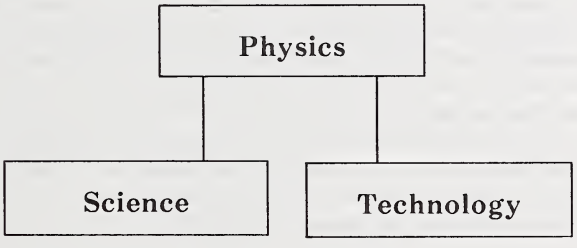

Figure 6. Physics Classified as Science and Technology

Even if we accept this argument, the consensus at this time is that the content in any science course and, in particular, in the discipline-oriented science courses, should be mostly science and a small amount of technology. Quantitatively, the changes to a science curriculum, through introducing a technology emphasis in some units of study, are minor; qualitatively the changes are major and fundamental.

Understanding the difference between science and technology is not only important to the study of science, it is also important to the understanding of any STS issue with which we are confronted. More and more of the issues that are presented to citizens in developed countries are technology related. Among those who study our way of life closely are those who believe that technology is the main agent shaping our way of thinking and acting. Jacques Ellul, the French philosopher, for example, indicates that the "technological phenomenon" has evolved since it appeared as a real force in the posteighteenth-century era. Ellul (1981) suggests that civilizations have progressed through three successive milieus: the natural milieu, the milieu of society, and now, the milieu of

technology. For Ellul technology has become both an environment and a system—an encompassing part of our life and lifestyle.

"In every VoSTS statement for which it was necessary to distinguish between science and technology in order to respond adequately to the statement, students overwhelmingly failed to do so. Science and technology were dealt with as a unified enterprise—technoscience—affecting our society. Formal definitions of the role of each enterprise were not used by students."

Reg Fleming (1987: 184)

Evidence indicates that more of our science students end up in technology-related careers than in (pure) science-related careers (even more, if you include business, industry and homemaking careers that are all increasingly technological in nature). There is also evidence to suggest that students and adults generally do not understand the difference between science and technology. A University of Saskatchewan survey (Fleming 1987) of students' beliefs using a **Views on Science-Technology-Society** (**VoSTS**) method, found that students do not differentiate between science and technology and that they transfer attributes of one to the other.

The conclusion that seems to be called for is that the academic study of technology should be mandatory. The problem is that most of us, as a result of our schooling, are uninformed about the nature of technology and of the fundamental differences and interactions between science and technology. Once we are informed, we still must decide on the scope and sequence of teaching students about technology at each level. What images of technology, for example, should be presented to a student in Grade 7 or to one in Grade 12?

"The prospective engineer and technologist are poorly served by current science education. ... The typical student ends his secondary education with a distorted view of science and virtually no concept of engineering and technology. And yet this is the student's preparation for the 21st century. It is not even appropriate for the 20th century!"

Donald A. George (1981: 15, 22)

A collaborative proposal headed by Alberta Education (Popowich et al. 1984) suggested guidelines for the "integration of technology in the Alberta science curriculum." The proposal called for science-technology literacy "to the end that future citizens become more competent at dealing with science and technology in our modern world (and theirs)." The means suggested for including technology components in the science curriculum emphasized a systematic and integrated approach. The means currently being advocated by Alberta Education include using STS and curriculum emphases to systematically integrate technology into the science curriculum.

Seven dimensions of technological literacy should be systematically integrated into the science curriculum, as technology curriculum emphases.

Components of a Technology Curriculum Emphasis

1. Technological knowledge
2. Technological skills
3. Technological problem solving and design
4. Technological attitudes
5. Technology in science
6. Technology in society
7. Nature of technology

The components of a technology curriculum emphasis listed above can be matched individually or in any combination and to any extent to units of study in a science course. At the lower grade levels or when introducing a new topic at higher grade levels, the technological emphases may be restricted in number and extent. The opportunities that present themselves naturally should be taken advantage of at all levels. For example, the development and description of the microscope (as a *technological product*) is a common curriculum component at the junior high school level. The next step might be to introduce the *technological skills* necessary to operate a microscope. In a subsequent topic the microscope might be used in a *technological problem solving* context. The evolution of the concept of microscopy to include a case study of the development and applications of the electron microscope might follow at a higher level. The contribution of the electron microscope to pure science and/or to society can involve a single-sentence comment in the classroom or can expand into a *case study* of the interrelated and extensive effect that this technology has had on either or both *science and society*. At an even higher level, perhaps at the postsecondary level, the reality of what is seen by an electron microscope might be debated at a philosophical level. The point is that the microscope can be used as a point of departure for a technology curriculum emphasis on technological applications, skills, problem solving, design and/or interaction with science and society. This opportunity arises for most technology used or studied in science courses. Teachers, textbook authors and curriculum designers can use these opportunities to integrate technology into the science curriculum in a systematic and evolutionary way. Each of the possible components of a technology curriculum emphasis is described below.

> *"Not only should all persons be equipped with a measure of scientific and technological literacy for meaningful life in a continually evolving society, but the non-technologists, engaged in policy and decision making at different levels need to be inducted to technology."*
>
> *UNESCO 1981 Congress on Science and Technology Education*
>
> (Quoted in Integration of Technology in the Alberta Science Curriculum—A Proposal, Popowich et al. 1984: 5)

1. Technological Knowledge

In a unit of study emphasizing technology, knowledge is usually based on concepts and descriptions. Conceptual knowledge includes technological products and processes as well as concepts about the nature of technology. For example, baking soda and automobiles are technological products, while the Solvay Process for producing baking soda and the assembly line for automobiles are technological processes. In the textbooks of the 1950s technological concepts and descriptions were common and the descriptions often had to be memorized; e.g., the blast furnace. In STS textbooks of the 1980s technological concepts and descriptions are generally presented as contexts for questions about and case studies of technology. The emphasis is now shifting to the nature of technology, comparisons of science and technology and their interactions, and the concepts of technological design and problem solving. This new orientation to technology will undoubtedly require time for curriculum designers, authors and teachers to develop an appropriate scope and sequence for each grade level.

Subconcepts presented in curricula through technological case studies often include input, output and feedback loops, and also raw materials, primary products and by-products. Case studies can also be used to introduce these terms and concepts without placing the emphasis on memorizing the intricacies of the technological product or process. The emphasis is, instead, on the generalized language and concepts that can be applied to many other technological systems. With technology changing so quickly, general concepts are potentially more important than specific details of the technology. These general concepts are also transferable to an emphasis on technological design, whether the emphasis is on the critical or creative aspect of design.

James Rutherford, of the American Association for the Advancement of Science (AAAS) and the National Science Foundation (NSF) Project 2061, suggests (1988) the following concepts should be emphasized in schools as we approach the 21st century.

Technological Concepts

1. An understanding of the nature of the dependence of science on technology, of technology on science, and why that partnership is so productive.
2. An awareness that technology develops in response to social needs and that, in turn, society is shaped by technology.

3. A recognition that technology *by its very nature* is a complex activity involving invention, engineering, science, mathematics, economics and values.
4. Understanding such concepts as benefit, risk, cost (monetary, social, environmental), side effect and trade-off.

The incorporation of these concepts about technology is a long-term undertaking; this is underlined by the choice of the year 2061 (the year of the return of Halley's comet) in the title of Project 2061. The concepts are described in more detail in the sections that follow.

2. Technological Skills

The introduction of technological skills in the curriculum is appropriate at all levels of science education. Technological skills (as opposed to process skills) may be defined as those skills necessary to operate a technology; e.g., a laboratory balance, a microscope or a multimeter. Technological skills have typically been subsumed within the scientific, psychomotor or manipulative skill component of a curriculum model. Separating technological skills from scientific skills, even though the distinction may be arbitrary, shows the mutual dependence of science and technology. Not only are technological skills important to a scientist, but increasingly, scientific research involves teamwork among scientists, engineers and technologists. The technological skills necessary to do research are increasingly provided by technologists and not by the scientists themselves.

For the purpose of organizing our knowledge about technology, it is useful to separate technological skills from technological process skills. Technological process skills are conveniently defined as those skills necessary to technological problem solving. Although there are many similarities between scientific and technological process skills, there are also some fairly distinct differences. Some of the similarities are discussed below in the context of technological problem solving.

3. Technological Problem Solving

To meet objectives in each of the dimensions of technological literacy, a systematic plan outlining the scope and sequence of each of the dimensions at each grade level is necessary. For example, what kinds of technological skills, technological process skills and scientific knowledge are prerequisite to presenting students with a particular problem in technological design? And, how much understanding of technological problem solving is necessary before students tackle a problem

to design a technological product or process? The answers to these questions depend on the grade and ability of the students involved. However, the process is somewhat developmental; students who have had no previous experience in technological problem solving are at a disadvantage compared to students with experience. The most obvious difference between scientific problem solving and technological problem solving is that predictions for the former are primarily driven by scientific concepts while the latter are primarily driven by experience.

In schools the experience necessary for technological problem solving is often generated from within the laboratory experience provided for by the curriculum. The students often gain the experience through systematic trial and error; the next prediction, procedure, evidence and analysis cycle that is attempted is determined by the experience gained in previous trials. For science teachers this approach requires a reorientation. Scientific problem solving in schools usually, rightly or wrongly, employs a more linear, single-trial approach. One could argue that the technological problem-solving model (e.g., systematic trial and error) has more transfer value to everyday problem solving and even to realistic scientific problem solving than the standard scientific problem-solving model that is employed in schools.

The design of a bridge from popsicle sticks or the design of a battery from everyday components or the design of a hardy fruit tree for Alberta are examples of the design of technological products. Each of these design problems has several answers that have varying acceptability. *Creativity* is fostered because not everybody has to get the same answer; *critical thinking* is fostered because each design can be evaluated and analysed and then redesigned. Failure is more acceptable because the focus is on the problem-solving process rather than exclusively on the product. Experience in the classroom indicates that a wide range of students seem to really enjoy technological problem solving. The motivational factor is significant when deciding whether to include these kinds of experiences in a science course.

The technological problem-solving model proposed by Alberta Education includes four broad steps. The processes and process skills incorporated in these basic steps depend on the kind of problem encountered and the level at which the students are operating.

Technological Problem Solving

1. **Understanding the problem**
2. **Developing the plan** (identifying the alternatives and planning and designing)
3. **Carrying out the plan** (testing the design and trouble shooting)
4. **Evaluating** (evaluating the design and evaluating the planning process)

The most significant attribute of technological problem solving for students is that the problem is more open-ended. There are usually many answers to the problem; there is always a "better mouse trap" to be invented.

Ultimately, however, it is important that we stop focusing on the differences and, even the similarities, between scientific and technological problem solving and begin to fuse the strengths of the two approaches. Before we can accomplish this integration, we must understand the nature of both scientific and technological problem solving. We must provide students with a systematic scope and sequence of curriculum experiences involving problem solving of different kinds, and then present a set of problems that require elements of all the problem-solving approaches. In a world where problems are becoming more and more complex, we need to build toward meeting this important goal of education. The attributes of technological problem solving that make it important to science education in particular, and education in general, are the increased access to critical and creative thinking and the increased transferability to other forms of problem solving.

4. Technological Attitudes

From experiences with technological problem solving, students gain attitudes or predispositions to act in a certain way when confronted with technological problems. Perhaps the most significant attitudes developed are the confidence and perseverance that come from tackling a problem and being given the opportunity to try and try again. Some technological attitudes that engineers, technicians and inventors display or ought to display are listed below.

Technological Attitudes

1. **Perseverance** in the face of failure
2. **Confidence** in personal ability
3. **Critical mindedness**; i.e., evaluates all solutions
4. **Creative disposition;** i.e., creates and tries new solutions

5. **Confidence** in technological fixes; i.e., technology has a potential answer
6. **Appreciation for alternative perspectives** on technology; e.g., ecological and aesthetic

Technological attitudes may be a new entry in the science curriculum priorities but the specific attitudes listed above are not new. Science teachers have recognized the importance of these attitudes for some time and have illustrated these attitudes by relating the stories about the invention of the telephone by Alexander Graham Bell and of the light bulb by Thomas Edison. The difference now is that the attitudes can be *systematically* approached through a technology curriculum emphasis as well as through a science emphasis. The technological attitudes listed above have now found another *explicit* place in the science curriculum and another effective means of achieving these attitudinal objectives.

5. Technology in Science

The concepts about and experiences with science and technology that are provided to students in an STS program challenge the old notion that technology is merely "applied science." Examples of technology that preceded any scientific understanding (e.g., metallurgy and batteries) may be presented in programs of study to indicate that there are many kinds of interactions between science and technology, but most assuredly technology is not just applied science.

"Many inventions evolve independently of science. ... Some such as the wheel even predate science as we know it. ... Science and technology are symbiotic, and it is naive to consider one the stepchild of the other. ... Science and technology are partners."

Craig N. Locatis (1988: 3-4)

The relationship of science and technology has evolved over the years. Previous to the 20th century most technology evolved independent of science as we know it. If anything, science was very dependent on the advances of technology. For example, the technological invention of the battery allowed for scientific advances in the electrolytic decomposition of compounds into elements. The scientific explanation of the battery did not come until about 100 years after its invention by Volta. In the 20th century, science and technology have steered parallel symbiotic paths with science leading technology in some areas and at some times and vice versa. Sometimes technology is developed independent of pure science and sometimes the development of technology is dependent on old or new scientific concepts. For example, the recent technological advance of ceramic superconductors far outstripped the ability of any modern theory to explain or predict the high temperature superconductivity that has been achieved. The back and forth swing of the lead between science and technology is a healthy and mutually beneficial relationship.

Science cannot function these days without a whole range of technological products and processes. In fact certain scientific advances have had to wait on the development of technology in order to test predictions made by newly proposed scientific concepts. For example, evidence for the existence of super-heavy W-particles had to wait until recently for the technological means of testing the prediction. The dependence of science on technology is increasing. The use of high-tech equipment in science is not only important to the empirical scientists in their work, but the theoreticians would not be able to advance their work without the means to test the predictions from their new concepts. This technology and science relationship is not well known outside the scientific community, but, the effect of technology on society is something of which every citizen should be aware.

6. Technology in Society

Technology has had a tremendous impact on our society. Many historians and philosophers have begun to examine technology as an agent of change in our society. Inventions such as the wheel, plow, steam engine, printing press, ship, electricity, medicines, automobile, assembly line, airplane, telephone and computer have had a tremendous direct or indirect effect on our lifestyles. One of the newest and most active areas of study in history, sociology, anthropology and philosophy centres on the effect of technology on societies.

There is, of course, considerable debate about the application of technology to achieve sensitive goals; e.g., nuclear and chemical warfare, birth control, abortion, drugs, genetic engineering, food additives, pesticides and animal experimentation. In the past, citizens have had little to say about the application of technology to solving problems of many descriptions. Recently we have been asking, and in some cases demanding, to be consulted on issues such as road construction, parks management, waste disposal and nuclear power. This involvement requires a different kind of schooling, especially in social studies and science courses. Understanding concepts such as benefit and risk, monetary, social and environmental cost, spinoffs and side effects, and trade-offs, will be essential for citizens in the 21st century.

> *"Science and technology have immeasurably enriched our material lives. If we are to realize the immense potential of a society living in harmony with the systems and artifacts which it has created, we must learn—and learn soon—to use science and technology to enrich our intellectual lives."*
>
> *James Burke (1978: 295)*

In science courses the curriculum must allow for instruction dealing with controversial technological issues and the role of science in suggesting scientific and non-scientific alternatives that may be more acceptable. Scientific and technological fixes

are not always the most suitable solutions and yet our society has become accustomed to leaning on science and technology for quick and easy solutions. Technology, as used by society, creates a problem (e.g., ozone depletion or the greenhouse effect) and then technology and science are expected to correct the problem. What we are gradually learning is that society has to gain control over technology instead of the other way around. This is a new problem with an increasing level of severity and it demands a new kind of technological literacy among the general public and its leaders. Schools must develop a new kind of science curriculum—one that involves a technological literacy component.

"The objective of genetic engineering technology is to improve the efficiency and productive output of plants and domestic animals. Efficiency and productivity, however, are cultural values, not ecological values."

Jeremy Rifkin (1987: 119)

7. Nature of Technology

The origins, limitations and nature of technological knowledge are somewhat different than the origins, limitations and nature of scientific knowledge. The epistemological investigation of how technological knowledge comes to be accepted by the engineering community uncovers different criteria used to evaluate technological knowledge than those used to evaluate scientific knowledge. For example, technological concepts may be evaluated in terms of their *economic viability*, *efficiency*, *reliability* and *simplicity*, whereas scientific concepts may be evaluated in terms of their ability to describe, explain and predict in a simple fashion. If we expect students to use higher mental processes and thinking skills such as evaluation, then they will need help to identify the general criteria by which scientific and technological concepts are judged.

"The technological phenomenon is characterized by evaluations of technologies ... in terms of [the] criterion of efficiency."

Jacques Ellul (1981: 37)

At an even higher level of sophistication concerning potential technology components for a science education, we might present alternative concepts of the nature of technology; e.g., those presented by philosophers and writers such as Jacques Ellul, Jeremy Rifkin and James Burke. Just as there are alternative concepts of the nature of matter, there are alternative concepts of the nature of science and of technology. Many educators claim that to live in a technological society without understanding the nature of technology and the nature of the interactions of technology with science and with society is inexplicable and indefensible. Classroom research and experience will eventually define the scope and sequence for the technology components of science education.

8. Summary

Are there any current examples of curriculum projects and programs of study that employ a technological curriculum emphasis? In postsecondary institutions one could immediately point to engineering faculties at universities and to institutes of technology across the country. But what about

secondary schools? Yes, the SaTiS Project in Britain and the secondary science curriculum in Alberta employ technological modules and curriculum emphases, respectively, to convey some of the objectives of the technology curriculum emphases described above. The annual Technological Literacy Conference in the U.S.A. provides evidence of the widespread and evolving focus on technology in all parts of the school and postsecondary curricula.

Although most of the technological literacy movement is intertwined with the STS movement, technological literacy has become a political and economic issue in most of the developed and developing countries of the world. Technological literacy should be and can be integrated into the science curriculum by using the conceptual organizers—STS and curriculum emphases. The description of a technology curriculum emphasis in terms of components is not intended to fragment the technological education of students, but to show that there are many pieces to the puzzle, and that all the pieces must be integrated in a curriculum to give students the kind of education they need for careers and citizenship in the 21st century.

"Science should be taught at all levels of school with an emphasis and focus on the relationship of science, technology and society in order to increase the scientific literacy of all citizens."

Science Council of Canada (1984: 38)

Society Curriculum Emphasis

The Science Council of Canada (1984) indicated in **Science for Every Student: Educating Canadians for Tomorrow's World** that the major findings of a four-year study of science education across Canada concerned the gap between the intents and the achievements of science education. One of the discrepancies identified was that "very little is being taught about the crucial interaction among science, technology and society," even though this is one of the objectives of science education in all jurisdictions across Canada. Therefore, one of the recommendations for renewal presented in the Science Council of Canada report concerned the STS connections.

In a discussion paper written for the Science Council of Canada Study, Aikenhead (1980) indicated that most science curricula were socially and culturally sterile and that students were not being prepared for their social responsibilities as citizens in an era characterized by science and technology. In his award-winning article, ("Collective Decision Making in the Social Context of Science," 1985) and innovative textbooks (**Science: A Way of Knowing**, 1975 and **LoRST: Logical Reasoning in Science and Technology**, 1990), Aikenhead maintains that Canadian science education must be reoriented toward providing students with a thoughtful strategy for decision making and that prerequisite to making decisions on STS issues is a knowledge of the characteristics and limitations of science and technology. The realization that STS decision making requires knowledge of and experience with the characteristics and limitations of science and technology supports this monograph's definition of a unified STS science education. A balanced STS science education needs separate curriculum emphases in science, technology and society, in order to build toward full STS literacy.

Just as there are a variety of components in science and technology curriculum emphases, there are similar components to a society curriculum emphasis attached to a unit of study in a science course. A society curriculum emphasis can vary in the extent of integration with the standard content, in the level of instruction, in the number of decision-making steps, and in the depth of each step of the decision-making model. These curriculum and instructional decisions provide for a wide variety of components for society curriculum emphases for science courses at all levels. Some of the possibilities are listed below.

Components of a Society Curriculum Emphasis

1. Societal knowledge
2. Societal skills
3. Societal attitudes
4. Societal decision making
5. Science and society

A society curriculum emphasis can be a relatively unrestricted version including the full range of essential learning (knowledge, skills and attitudes) or a restricted version including only the skills of STS-issue decision making. In the latter case the curriculum emphasis is often described as a science and technology in society (STS) emphasis with decision making on an STS issue as a focus. Examples of STS issues include genetic engineering, chemical warfare, toxic waste disposal, nuclear energy and combustion of fossil fuels. At the lowest level of coverage, students are made aware of what an STS issue is and that STS issues are appearing in the news at an increasing rate. Next, students are usually made aware that the scientific perspective is just one of many perspectives that may be taken on an STS issue. Beyond this initial awareness stage, a variety of curricular and instructional strategies are available to teachers.

1. Societal Knowledge

The quantity of societal knowledge (i.e., societal concepts and descriptions) covered in a science program is generally minimal. Perspectives on an STS issue is one example of a societal concept that is usually presented to students in an STS science course. The description of an STS issue is often restricted to half a dozen perspectives initially and then expanded to a dozen perspectives on an issue as students become proficient using the concept of perspectives.

> *"I know no safe depository of the ultimate powers of the society but the people themselves; and if we think them not enlightened enough to exercise their control with a wholesome discretion, the remedy is not to take it from them, but to inform their discretion by education."*
>
> *Thomas Jefferson*

2. Societal Skills

Each process or step of an STS decision-making model involves the use of skills that are similar and yet different from the scientific and technological problem-solving skills discussed above. Teachers cannot assume that analysis and evaluation skills learned in a scientific problem-solving context will be automatically transferred to an STS decision-making context. Just as scientific and technological skills have various levels of attainment, the skills used in the context of societal decision making are developed at various levels. The Alberta Education junior high school Consensus Building Model for social issues, for example, identifies three levels of skill development.

Levels of STS Decision-making Skills

1. **Awareness level**—the teacher uses the skill and models the skill through teaching
2. **Instructional level**—the skill is taught to students through planned learning experiences
3. **Independent level**—the skill should be maintained and developed through review and application

As with most developmental models in education, the model is not meant to indicate that at the higher grade levels only the independent level of skill attainment should be employed. Just as Alberta Education monographs on physical, social and cognitive growth have indicated that skill development in these spheres in a new context usually requires going back to basic awareness and concrete levels, the attainment of new STS skills also requires starting at an awareness and instructional level before advancing to an independent level of attainment. Although an older skill can reach new levels at a higher grade, experience and research indicate that newer skills must progress through the awareness, instructional and independent levels. The independent level may or may not be reached at any particular grade level. (See Figure 7.)

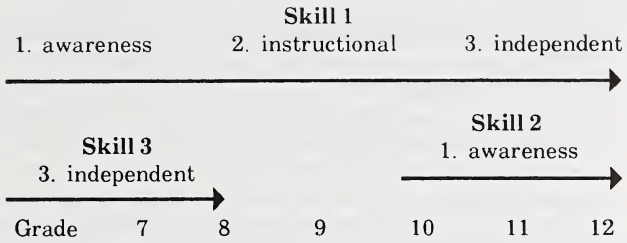

Figure 7. Levels of Skill Development With Grade Level

The skills required for thoughtful decision making or consensus making on STS issues in a science course are similar to those used in social studies courses. Social inquiry and participation skills used in social studies decision making are listed below.

Social Studies Decision-making Processes

1. Identify and focus on the issue
2. Formulate research questions
3. Gather and organize data
4. Analyse and evaluate data
5. Synthesize data
6. Resolve the issue
7. Apply the decision
8. Evaluate the decision, the process and the action

These are similar to scientific problem-solving skills. For example, both activities involve formulating questions, gathering evidence and using higher mental processes such as analysis, evaluation and synthesis. A major difference is that the context for the research is usually the library rather than the laboratory. Students gather evidence to support various stances from newspapers, magazines, original documents, government publications and study reports. As with all skills, they must be practised—experience with process skills is vital to their application in a problem-solving or decision-making context. To emphasize the importance of experience to the development of process skills it has been suggested that the definition of process skills should be restricted to the skills portrayed by students in a research situation (Jenkins 1987). This definition alleviates the tendency to teach process skills by lectures rather than by experience. If process skills are valued then it is essential that these skills be defined in terms of what is experienced, not in terms of what someone else has experienced. Guidance can be provided, but unless students experience the process of problem solving or decision making on their own, the learning will likely be purely academic and non-transferable.

The kinds of skills involved in decision making range from classifying statements made on the pro and con sides of a debate (Aikenhead 1975; Jenkins 1981; Alberta Education 1988) to critical reflection on the interests of the participants and their platform (Aoki 1979). The higher level skills are most likely to remain the nearly exclusive domain of social studies courses, but science teachers will have to find the appropriate extent of skills to suit their students in their situation. For example, science teachers may decide to make students aware only of the process of critical reflection as used by critical theorists. These higher level skills are progressively more abstract but each new skill at each level of schooling must be introduced through the awareness level, to the instructional level, and, finally, on to the independent level. The general rule of moving from the concrete to the abstract applies equally well for each new process skill as it does for newly introduced concepts.

Since science teachers may be at an initial disadvantage in teaching decision making, they too must go through the same awareness, instruction and independent levels that students must. For this reason, Alberta Education is providing concrete examples and modelling of STS decision making through the use of videotapes and inservices and through the selection of support materials that provide the necessary assistance to teachers and students. Parallel to the introduction of decision-making skills for students is the introduction of new or renewed teaching skills for science teachers. The biggest difference is in the greater emphasis on leading discussions, particularly discussions that lead to no final resolution. An instructional emphasis on decision making might include some of the following tactics:

Decision-making Instructional Strategies

1. **Library research** e.g., reading and analysing newspapers, government reports and annual reports
2. **Classroom discussions** e.g., modelling of tolerance, understanding and respect for a variety of points of view
3. **Classroom debates** e.g., finding and expressing pro and con arguments from a variety of perspectives
4. **Townhouse role playing** e.g., identification of which individuals and groups hold power in a community
5. **Public interventions** e.g., writing a fictitious or real intervention to be sent to a public hearing on an STS issue
6. **Public hearings** e.g., attending public hearings, either as an intervenor or as a participant
7. **Case studies** e.g., studying a past case of a resolved STS issue or a new case of an unresolved issue with the strategy of moving from the awareness level through the instructional and independent levels of societal process skill development

Matching Instructional Strategies With Content

Not only can curriculum emphases be matched to units of study but instructional strategies can also be matched to a unit of study and its parallel curriculum emphasis. For example, it makes sense to match a laboratory instructional approach to the development of scientific process and problem-solving skills. For an emphasis on scientific concept development the newly developed constructivist instructional strategies might be appropriate (Rosalind Driver of Leeds, 1986; Ian Mitchell PEEL Project in Australia, 1986; Gaalen Erickson of UBC, 1987). For an emphasis on STS decision making it seems appropriate to suggest that the types of activities listed above would best fit. The concept of instructional strategies could be added to the concepts of STS and curriculum emphases to help science educators organize and present all the objectives of science education to students.

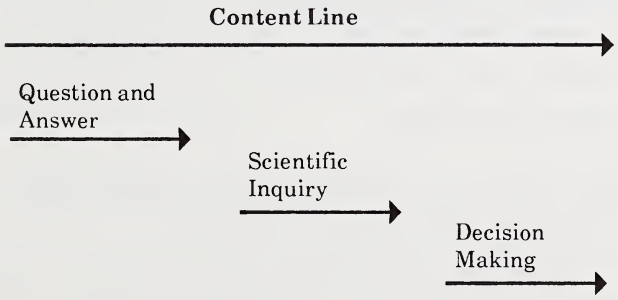

Figure 8. Matching Instructional Strategies with Content

The presentation of the content in a unit of study by several teaching techniques is illustrated in Figure 8. At certain points during the unit of study a different instructional strategy may be appropriate. Science teachers have been using a variety of instructional approaches for years. Some of these older instructional approaches are listed below, along with some new ones . Not only are a variety of instructional strategies needed to meet all the objectives for science education but the variety can also address the various learning styles of students.

Instructional Strategies in the Sciences

1. **Didactic** (lecturing) instructional emphasis—mainly a one-way presentation
2. **Questioning** instructional emphasis—a presentation that focuses on verbal questions and answers
3. **Empirical verification** instructional emphasis—demonstrations and laboratory work emphasizing verification
4. **Scientific inquiry** instructional emphasis—scientific problem solving for one or more periods of work
5. **Nature of science and technology** instructional emphasis—the language of the classroom and the discussions that precede and follow laboratory work emphasize the nature of scientific and technological work
6. **Decision making** instructional emphasis—involves discussions, role playing, interventions and computer simulations as instructional strategies
7. **Modelling** instructional emphasis—modelling of STS skills, attitudes and values through language and actions

Each of these instructional strategies requires commitment and skill and each deserves a place in the instruction of our students.

3. Societal Attitudes

Societal attitudes are relatively new as an explicit curriculum emphasis in the science curriculum. Societal attitudes, in an STS science curriculum, refer to the attitudes or predispositions that are brought to the decision-making context. These attitudes set the tone and quality of the discussions and debate, and, as such, are very important to what Aikenhead (1985) calls thoughtful and vigilant decision making. Some of the attitudes that affect the quality of decision making are listed below.

Societal (Decision-making) Attitudes

1. **Tolerance** for alternative perspectives—acceptance of the need for alternative perspectives
2. **Commitment to understanding** alternative perspectives—reading about and listening to all perspectives
3. **Respect** for alternative perspectives—displaying more than tolerance for a perspective
4. **Confidence** in thoughtful decision making—confidence in personal ability to make thoughtful decisions
5. **Vigilance** in pursuing thoughtful decisions—committed to achieving a thoughtful decision
6. **Appreciation and respect** (for thoughtful decisions)
7. **Commitment to understanding the roles and limitations** of scientific and technological contributions to decision making on STS issues

In a science classroom teachers can make only a small contribution to the students' attitudes of tolerance, respect and commitment to the understanding of alternative points of view. However, science curricula and instruction should be able to make a more significant contribution to the latter attitudes listed above—confidence and vigilance in decision making and commitment to understanding the roles of science and technology in decision making on STS issues.

If there is ever to be any chance of science students transferring scientific attitudes, such as critical-mindedness, open-mindedness, respect for evidence and suspended judgment, to real situations, then the practice of these predispositions in an STS decision-making context might just be the instructional strategy needed. However, if the instructional emphasis in a unit of study with a society curriculum emphasis is strictly didactic (lecture), then the potential of the program of studies for meeting this objective will not likely be realized. The task of curriculum designers is to provide the time; the task of the classroom teacher is to use the time provided to meet this attitudinal objective; and the task of the test construction specialist is to find ways to recognize and reward the students who have achieved these goals of science education.

"An effective decision maker is one who shows vigilance in searching for information, carefully evaluating the validity and reliability of that information, and generally feeling committed to achieving a thoughtful decision."

Glen Aikenhead (1985: 464)

4. Societal Decision Making

The concept of STS decision making (like all concepts) has several subconcepts. Curriculum developers and teachers must consider which subconcepts can be introduced and to what extent at each grade level. By the time students have learned the basic subconcepts in the lower grades, fairly sophisticated decision-making concepts and skills can be introduced at higher grade levels. For example, students at lower grade levels can learn to identify and classify a restricted number of (e.g., four or five) perspectives that can be taken on an STS issue. These perspectives might include economic, technological, political and ecological at an initial level. Classification is an exercise that can be done by students operating at a fairly low psychological level; e.g., a concrete operations cognitive level. To become involved in the analysis, evaluation and synthesis levels of abstract thought, students must be brought along in a series of systematic learning cycles.

Although it is generally not wise to subscribe to a problem-solving or decision-making model that appears to be linear, one such model is presented below. There are many similar models that communicate approximately the same concept of STS decision making. Like a map of an area, the model does not portray the real thing. However, the model, like the map, can be useful as a restricted guide to help us get where we want to go. The model needs to be linear, cyclic and involve parallel streams of activity all at the same time; i.e., it needs to reflect the complexity and flexibility of real decision making. As no map can, no model can totally reflect the real thing, but it is still useful—as long as we do not get too tied to it.

Note the similarity to the scientific problem-solving model. For initial comfort and confidence, teachers may wish to emphasize the similarities in the models before attending to the differences.

An STS Decision-making Model

1. Being aware of or identifying the existence of an STS issue (i.e., problem)
2. Deciding on an appropriate decision-making approach (i.e., experimental design)
3. Gathering evidence to support all sides in an STS debate (i.e., evidence)
4. Using the concept of perspectives to classify statements made on a STS issue (i.e., analysis)
5. Analysing the number and kind of perspective statements made on an STS issue (i.e., analysis)
6. Making and acting on a decision on an STS issue (i.e., synthesis)
7. Evaluating the processes and products of an STS decision (i.e., evaluation)

Although the sequential nature of an STS decision-making model can be seen in the above list of potential components of an STS decision-making model, each of these components may be learned and practised separately. Just as stoichiometric problems in chemistry, inclined plane problems in physics and ecology problems in biology involve multiple steps and subconcepts that may be learned and practised separately, societal decision making involves multiple steps that may be learned separately and applied in totality at various levels of sophistication. For example, the above model may be used in elementary, junior high or senior high school if the teacher takes care to provide the appropriate amount of help and to adjust the expectations accordingly. Case studies and modelling provided by the teacher and by the curriculum support materials are necessary at each step and at each level of sophistication. (Recall the awareness, instructional and independent levels of achievement of skills discussed above.)

The identification and classification of perspectives on an issue is a way to start. Classroom experience in the **Science: A Way of Knowing** (1975) and the **STSC Chemistry** (1988) projects has indicated that students at the Grade 10 level can

handle the use and/or invention of a classification system for statements made on an STS issue. The statements are understood as coming from a broad spectrum of our society. If the statements are gathered and analysed, patterns are apparent—a variety of perspectives or points of view on the STS issue appear. The perspectives uncovered by students in the past are listed below.

Perspectives on an STS Issue

1. **aesthetic** – artistic, tasteful, beautiful
2. **ecological** – environmental
3. **economic** – monetary
4. **emotional** – feelings
5. **ethical** – moral
6. **legal** – jurisprudence
7. **militaristic** – warfare, defence
8. **mystical** – unexplainable
9. **political** – vote getting
10. **scientific** – research
11. **social** – community
12. **technological** – technical

There is nothing sacred about this classification scheme, but it works. Anecdotal evidence from the classroom indicates that students are able to use the system successfully, and it allows one to differentiate between observations and interpretations in a context other than science. For example, when politicians call for more research on acid rain, one is forced to classify this statement as scientific, regardless of second guessing (interpretations) of motives or hidden agendas. The classification of statements is an initial step that can lead to further classification of the statements as positive or negative (pro or con) to a resolution in a debate on an STS issue. For example, an ecological statement on nuclear power might be either positive or negative relative to the resolution that nuclear power be banned.

– *"There have been many accidents associated with nuclear power where radiation has been released into the environment."*

\+ *"Nuclear power has replaced coal-fired power plants and has reduced acid rain in central and eastern Canada."*

Students can carry this classification tactic further by gathering all the pro and con statements they can find and analysing the results by tallying the number of each. Simplistically, the analysis provides them with an answer to their question. However, an evaluation by the students of the

decision-making design leads to the realization that a straight objective tally of the statements is not acceptable to everyone. This leads to a discussion of values and the amount of value placed on certain perspectives by segments of our society. Aikenhead (1985) handles this by presenting his students with the concept of social domains impinging on decision making. Aikenhead's classification of domains is presented in Figure 9.

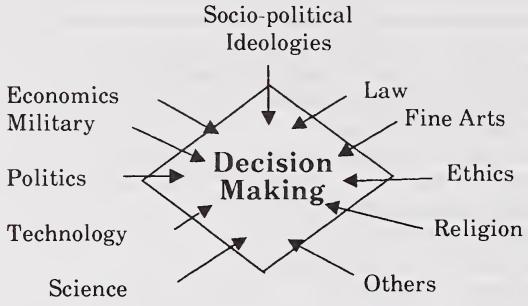

Figure 9. Social Domains Impinging on Decision Making

One of the advantages of the domain classification approach is that students have a rare opportunity to reflect on the basis for each of these aspects of society. Aikenhead indicates that each domain has its own knowledge base, its own assumptions underlying the knowledge base, its own traditions for decision making, its own purpose in society and its own world view. In a science course this understanding would likely be simplistic, but to understand the characteristics and limitations of science and of technology one must have the opportunity to study the characteristics of alternative domains of knowledge. Besides achieving this objective, students can also use this classification scheme to identify the domain that holds the social and/or political power to make the decision on an STS issue.

The idea of perspectives and social domains was used by Capra (1982), a physicist turned philosopher, to make an important point about the narrow view that experts in our society have on problems and issues. Capra's point is that many economists, for example, are not able to understand and predict our economy because they fail to take a multiperspective view of the world. These economists, says Capra, fail to take environmental, social, political and ethical factors into account when developing their concepts of the economy. Times are changing, however, and engineers, lawmakers and others are learning to consider many points of view on an issue and to evaluate technological products and laws from each of these points of view. It seems appropriate that the concept of a multiperspective view should be part of the schooling that students are exposed to now.

The task of the science educator is to show how, where and to what extent scientific and technological knowledge can be used to help answer STS questions. Scientific knowledge has a role, although limited, to play in STS decision making. Our task as teachers is to define that role and to provide some models for, and some practice with, STS decision making. Problem solving in society and in the scientific community has long passed the stage where an individual can be expected to provide a suitable answer. Complex scientific problems require a research team of scientists, engineers and technicians to help solve them. Some observers claim that to teach our students otherwise by omission is a grave error. Likewise, a complex STS problem requires a team of science, technology and society representatives to provide a thoughtful and defensible solution to the problem. Better yet, each of the science, technology and society representatives should have an understanding of and a tolerance for alternative perspectives on an issue. Respect for another's position on an issue is a major prerequisite for the solution of any STS problem.

"Most academics subscribe to narrow perspectives of reality which are inadequate for dealing with the major problems of our time. ... To understand our multifaceted cultural crisis we need to adopt an extremely broad point of view and see our situation in the context of human cultural evolution."

Fritjof Capra (1982: 25)

In addition, the concepts of consensus, collective decision making at the global, personal and scientific level, values, trade-offs and deliberation are all necessary to an understanding of decision making in general and of the role and limitations of science and technology in particular. Each of these concepts must be slowly, deliberately and systematically introduced to the science curriculum at each grade and ability level. To do otherwise is to not provide an adequate education for 21st-century students.

5. Science in Society

Science in society has changed significantly over the last few decades. The state of flux in the interactions between science and society has led to many debates and to many false starts in setting up the new rules for the science and society game. Some of the concerns and problems are listed below.

Science in Society Problems

1. Science and technology are treated by society as technoscience; i.e., they are not differentiated. (Fleming 1987)
2. The funding for scientific research is increasingly based on the same type of criteria as technological research and development (R & D). (Polanyi 1988)
3. In some developed countries half the scientific community is employed in military (R & D). (Suzuki 1989)
4. The fight for the decreasing amount of research funding is consuming an inordinate amount of researchers' time and efforts. (Savan 1988)

5. The fight for research funding may be changing the face of the scientific community and increasing the breaches of ethics in the scientific community. (Savan 1988)
6. The courts and society in general are having difficulty understanding scientific values, expressions of uncertainty and the conflicts within the scientific community. (Aikenhead 1985)
7. There are public and private versions of science that reflect what scientists do and say in public versus private. (Holton 1978; Polanyi 1958)
8. The scientific community is in some instances governed internally by powerful vested interests that displace the fulcrum that balances scientific authority and challenges to the status quo. (Ravetz 1971)
9. Scientists are affected by cultural values when testifying on behalf of the pro or con side of an STS issue—especially if they are uncertain of their scientific answers. (Gaskell 1982)

Since C.P. Snow (1961), an increasing number of philosophers, sociologists and anthropologists are writing about problems within the scientific community and between science and society (e.g., Ravetz 1971; Latour and Woolgar 1979). In general, school and undergraduate students do not have the opportunity to receive, discuss and debate these ideas. However, it is increasingly difficult to justify excluding from the curriculum the problems that exist between science and society and within the scientific community. Voters in our society are increasingly being asked to make judgments on STS issues and on the extent of funding for scientific and technological R & D. To make thoughtful decisions, leaders and voters must be aware of the internal workings and problems of the scientific community. Conflicts between science and society are in most cases a result of a lack of understanding of the characteristics and limitations of science. From an educational perspective this lack of understanding is correctable.

"Without fundamental changes in the structure of scientific training, advancement and rewards, we risk wasting one of our most valuable human and intellectual resources."

Beth Savan (1988: 15)

Mendelsohn (1976) suggests that science needs to be guided by a new set of values in order to interact in a valuable fashion with the expectations of society. It is a new time in the history of science and society and a new set of guidelines are needed for scientists as they interact with society. The values suggested by Mendelsohn are as follows:

Values for Science in Society

1. **Modesty**—replacing the arrogance of the past
2. **Accessibility**—demystifying science
3. **Humanistic and ethical research**—non-violent research
4. **Harmony with nature**—versus controlling and dominating nature

In response to these types of concerns there have been several major efforts by scientists, technologists and physicians to fight for these values. The establishment of the associations Scientists for Social Responsibility and Physicians for Social Responsibility are examples of the kinds of sincere efforts that have resulted in a major thrust toward having scientists and physicians align themselves with values that reflect a responsible and honest interaction with society. In a modern science curriculum, students should be made aware of these organizations, their genesis and their goals.

David Suzuki has advocated these values for years through his science in the media approach. Demystifying science was his initial aim, while recently, in the "A Planet for the Taking" television series, Suzuki has emphasized the values of modesty, ethics and harmony.

6. Summary

A society curriculum emphasis in a unit of study in a science program allows curriculum designers, student assessment personnel and teachers to systematically cover science and technology in society goals of science education in a manageable fashion. It is suggested that one of every three or four units of study in a science course should have decision making on STS issues as an integrated curriculum emphasis. A society curriculum emphasis would contain societal knowledge, skills (i.e., decision making) and attitudes in addition to the scientific content.

In some STS courses, STS issues are the focus of every unit of study. In the Alberta curriculum there is a recognition that a solid foundation of scientific and technological knowledge and an understanding of the nature of science and of scientific knowledge are prerequisite to making what Aikenhead (1985) calls a thoughtful decision. Making decisions on STS issues requires a concerted effort to meet all the prerequisite goals of science education. In a sense, STS decision making is the culmination of a successful science program.

Overview

"The role of science in society needs to be emphasized, with consideration given to the application of science, the social and environmental impact of scientific discoveries and the moral and ethical issues which accompany the use of scientific knowledge."

Alberta Education Review of Secondary Programs (1984)

The STS (science, technology and society) concept of curriculum has the potential for unifying many of the previous concepts of science education. As such, STS science education is an opportunity to organize and present all the goals of science education in a coherent package. When the STS science education concept is combined with the concept of curriculum emphases, we have a systematic and logical method for presenting STS goals over the total secondary science program. The total package of science, technology and society goals can be combined to serve the student who is going on in the sciences and, also, the total population of students who will become citizens of the age of science and technology.

An example of the potential of the STS and curriculum emphases concepts as applied to science education is *the prerequisite need for understanding the characteristics and limitations of science and technology* before thoughtful decisions on STS issues can be obtained. Science and technology curriculum emphases provide the prerequisite knowledge for decision making on STS issues in a unit of study with a society curriculum emphasis. This integrated and systematic approach to meeting all the goals of science education also allows for extending the quality of the goals to a level suitable for the 21st century. The model used in this monograph to represent the wide range of goals in science education is presented in Figure 10.

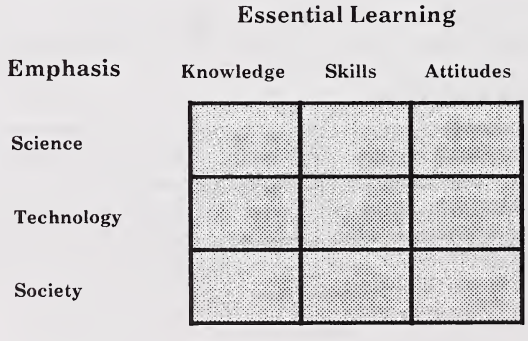

Figure 10. Knowledge, Skills and Attitudes in an STS Program of Studies

The main advantage gained by integrating the science, technology and society concept with the knowledge, skills and attitudes concept is that all the goals of science education can be presented in a simple, yet complete, manner. Educators involved in curriculum design, student assessment, teacher inservice and classroom teaching can use the model to ensure that all the goals of science education are being given the attention they deserve. All the forms of knowledge portrayed by the model deserve attention in all courses, but strategies for systematically including this essential learning are required.

The concept of curriculum emphases provides a general strategy for systematically integrating the goals of science education in a manner that is not overwhelming. Each unit of study in a course of studies is matched to a curriculum emphasis on a particular goal; e.g., a science, technology or society goal. For example, one unit of study might have a science curriculum emphasis on scientific process skills or the nature of science, while another unit of study emphasizes the nature of technology interactions. A third unit of study in the same course might focus on an STS issue and collective decision making. By combining the concept of science, technology and society with the concept of knowledge, skills and attitudes and the concept of curriculum emphases, all the goals of science education can be communicated to educators and then systematically presented to students in the classroom.

No model can ever fully represent a curriculum, but the model in use should reflect the current thinking and values of the education community and of society in general. The evolution of concepts and models of science education requires that the current concepts and models be clearly, consistently and logically presented to allow testing in the classroom. This monograph attempts to portray the complexity of science curricula in a simple yet complete manner. The concepts and models presented herein can be tested for their ability to describe and guide science education in our schools.

The bottom line in STS science education is that our students will be living and leading in the 21st century and that a different kind of scientist and a different kind of citizen will be required. We can live in the past with a 17th-century view of the nature of science and with a mid-1900s view of societal problem solving, or we can move into the 21st century with a systematically complex and unified curriculum that reflects the state of our evolution as civilized people. The STS concept and curriculum emphasis system provide us with an uncommon opportunity to achieve all the goals of science education in a program of studies from elementary through secondary schools. The opportunity is ours to grasp and use for the benefit of current and future generations.

> *"We are all afraid—for our confidence, for the future, for the world. That is the nature of the human imagination. Yet every man, every civilization, has gone forward because of its engagement with what it has set itself to do. The personal commitment of a man to his skill, the intellectual commitment and the emotional commitment as one, has made the Ascent of Man."*
>
> *Jacob Bronowski (1973: 438)*

Epilogue

Much of what appears in this monograph is restricted and adapted to fit existing structures and to fulfil a current purpose. Some reviewers indicated that the model presented was too complex while others thought it too simple. The main intent of the monograph is to combine separate concepts in a model that could be used to describe a balanced and unified science education. The concepts combined to produce a description of STS science curricula are curriculum emphases, knowledge, skills and attitudes, and units of study in science. The main challenge when combining concepts that may be used independently to describe curricula is to create a model that is logically consistent. While each dimension of a two-dimensional model must stand on its own in one dimension, each will be subsumed in the second dimension of the model. For example, in the STS monograph model, each curriculum emphasis must have logical and consistent knowledge, skill and attitude components. When this criterion is applied to the task of classifying the goals of education two things happen: some goals of education fit a broad curriculum emphasis (or are restricted components of a broad emphasis), and some components are obviously overlooked—consciously or not. An advantage of the model is that educators are forced to look at every potential component of the curriculum described by the model and to publicly state which components they value or do not.

The main difference between the model in this monograph and most descriptions of STS programs is that the model applies equally well to all kinds and levels of science courses and that not every unit of study begins with an STS issue. One could argue, however, that everything ends with an STS issue. After the prerequisite knowledge, skills and attitudes are developed from a scientific and technological perspective, students are then ready to tackle STS issues in a thoughtful and vigilant manner. The point made repeatedly in this monograph is that the prerequisite knowledge for STS decision making is not only scientific knowledge but also an understanding of the nature of scientific knowledge and of the interactions between science, technology and society.

The STS model presented could be even more encompassing and potentially more fruitful if it was expanded to include a curriculum emphasis on communication; i.e., science, technology, society and communication curriculum emphases for separate units of study. When communication is included, the resulting model can be used to describe not only science

courses with STS emphases, but also technology courses, social studies courses and language courses with appropriate amounts of STS knowledge, skills and attitudes. This extension provides an STS model with a much wider application than to just science courses. Once the idea of extending the model is introduced a variety of questions arise:

1. Can the extended model be used to make our standard discipline-oriented courses more interdisciplinary?
2. How must the model be modified to include mathematics?
3. Should a curriculum emphasis on thinking, meta-cognition, constructivism or learning-to-learn be added to the model to incorporate the growing concern for and attention to these basic goals of education?
4. Should problem solving (i.e., the use of processes and their component skills to obtain a solution in a specific context) replace skills in the knowledge, skills and attitudes triad?
5. Should epistemology (i.e., the study of the nature, origins and limitations of various forms of knowledge) be added to the knowledge, skills and attitudes dimension of essential learning?

These are all questions which, if answered, could lead to a more encompassing view of science education in particular and of education in general. The STS model is a human invention used to provide us with a better understanding and description of curricula. The invention of the model and its use depends on our values. The science curriculum will ultimately reflect what we value. Although the STS monograph may initially serve the purpose of describing STS curricula, the long-term goal is to stimulate reflection and discussion on the concepts presented, culminating in some action toward an appropriate education for our students.

"Creating a new theory [concept] is not like destroying an old barn and erecting a skyscraper in its place. It is rather like climbing a mountain, gaining new and wider views, discovering unexpected connections between our starting point and its rich environment. But the point from which we started still exists and can be seen, although it appears smaller and forms a tiny part of our broad view gained by the mastery of the obstacles on our adventurous way up."

Albert Einstein and Leopold Infeld (1938: 152)

Annotated Bibliography

This annotated bibliography has eight sections: Science, Technology, Society, STS and Curriculum Emphases, Sample STS Textbooks, STS Organizations, Periodicals and Conferences, Free STS Publications and STS Videos and Films.

Science

Association for Science Education. (1981). *Nature of Science.* Science in Society Reader Jo. London: Heinemann. ISBN: 0-435-54039-4
(Every science teacher should read this 67-paper booklet. The Bacon, Popper and Kuhn concepts of the nature of science are discussed.)

Einstein, Albert and Leopold Infeld. (1938). *The Evolution of Physics.* New York: Simon and Schuster.

Galbraith, Bernie. (1983). *Science Process Skills and the Alberta Science Curriculum: A Position Paper.* Edmonton: Alberta Education.
(Most Alberta schools have this document, which compares various process skill inventories.)

Hawking, Stephen W. (1988). *A Brief History of Time.* New York: Bantam Books. ISBN: 0-553-05340-X
(Hawking is considered by many to be our new Einstein. Be sure to read the first and last two chapters of this bestseller.)

Hodson, Derek. (1988). Toward a Philosophically More Valid Science Curriculum. *Science Education.* 72(1), 19–40.
(Hodson argues that curriculum reform has failed because teachers, like scientists, have "a scant understanding of scientific knowledge.")

Holton, Gerald. (1978). *The Scientific Imagination: Case Studies.* Cambridge: Cambridge University Press. ISBN: 0-521-21700-8(H) and 0-521-29237-9(S)
(Discusses the extensive process of evaluation and validation used by the scientific community, and the public and private process of creation.)

Kaplan, A. (1964). *The Conduct of Inquiry.* San Francisco: Chandler.

Kuhn, Thomas S. (1970). *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press. ISBN: 0–226–45803–2 (C), 0–226–45804–0 (P)
(This book is tough reading but is a classic reference not only for science readers but for those interested in the acceptance of knowledge in any discipline.)

Latour, Bruno and Steve Woolgar. (1979). *Laboratory Life: The Social Construction of Scientific Facts.* Beverly Hills: Sage Publications.
ISBN: 0-8039-0993-4(H) and 0-8039-0994-2(P)
(A sociological study of life in a science laboratory to reveal the private world of the scientist.)

Magee, Bryan. (1973). *Popper.* London: Fontana Press.
ISBN: 0-00-686008-7
(An excellent primer on Karl Popper's ideas about the nature of science—a must. If only one book on the nature of science were read, this is an excellent choice.)

Nadeau, Robert and Jacques Désautels. (1984). *Epistemology and the Teaching of Science.* Ottawa: Science Council of Canada.
ISBN: 0–662–13214–9
(Presents a range of concepts and descriptions of *what science is*; concludes with a call for the "epistemological revitalization of science teaching." Yields more with each reading—an excellent discussion of the alternative concepts of the nature of science.)

Nay, Marshall A. (1971). A Process Approach to Teaching Science. *Science Education,* 55(2), 197–205.
(An extensive elaboration of process-approach teaching including an inventory of processes in scientific inquiry.)

Nay, Marshall A. and Michael Kozlow. (1976). An Approach to Measuring Scientific Attitudes. *Science Education,* 60(2), 147–172.
(Besides identifying and describing scientific attitudes (predispositions), Nay and Kozlow have developed a "test" of scientific attitudes.)

Polanyi, Michael. (1958). *Personal Knowledge.* London: Routledge & Kegan Paul.
(Michael Polanyi is the father of Canadian Nobel laureate John Polanyi who continues in his father's footsteps to seek freedom from bureaucratic control for scientific research.)

Ravetz, Jerome R. (1971). *Scientific Knowledge and Its Social Problems.* London: Oxford University Press.
ISBN: 0-19-519721-6
(Ravetz's concept of the nature of the scientific enterprise includes the effect of internal and external social factors.)

Technology

Burke, James. (1978). *Connections.* London: MacMillan Publishers.
ISBN: 0-333-31924-9(P)
(This technology and society book accompanies the BBC video series, Connections, available from ACCESS. Burke looks at eight recent inventions that have "enormous potential for man's benefit—or his destruction.")

Ellul, Jacques. (1981). *Perspectives On Our Age*. Toronto: CBC Enterprises.
ISBN: 0-88794-094-3(B) and 0-88794-095-1(P)
(The French philosopher of technology, Ellul is internationally respected for his writing about the nature of technology and the general (and hidden) effects of technology on society. A small and easy book to read.)

Fleming, Reg W. (1987). High-school Graduates' Beliefs About Science-Technology-Society. *Science Education*, 71(2), 163–186.
(Fleming, from the University of Saskatchewan, writes about an empirical study that indicates that students confuse science and technology and do not understand the nature of these separate but interdependent enterprises.)

George, Donald A. (1981). *An Engineer's View of Science Education*. Ottawa: Science Council of Canada.
ISBN: 0-662-11598-8
(George laments the lack of technology perspective in the high school courses that prepare students to be engineers and technologists.)

Locatis, Craig N. (1988). Notes on the Nature of Technology. *The Technology Teacher*. April, 3–6.
(Articles on the nature of technology are scarce. This one is short, informative and easy to read.)

Popowich, Garry et al. (1984). *Integration of Technology in the Alberta Science Curriculum—A Proposal*. Edmonton: Alberta Education.
(Presents a rationale for integrating technological knowledge, skills and attitudes into science curricula. The concept of "science–technology literacy" and the six dimensions of technological literacy are well presented.)

Rifkin, Jeremy. (1987). Biotechnology Should Be Stopped. *Opposing Viewpoints—Sources: Volume 1-Science and Technology*. St. Paul: Greenhaven Press.
(This book of opposing viewpoints is excellent reading. The concept of Opposing Viewpoints is that for every STS issue there are opposing sides to the argument.)

Rutherford, F. James. (1988). STS . . . Here Today and . . . . *Bulletin of Science, Technology and Society*, 8(2), 126–127. University Park, PA: STS Press.
(Rutherford is a leading spokesman for STS. The bulletin from STS Press at University Park PA 16802 U.S.A. ($30) is worth subscribing to.)

Wriggleworth, J. Douglas and Graham Orpwood. (1988). *Technology and Innovation in Canadian Industry. An information kit for science teachers*. Toronto: Orpwood Associates.
(This booklet was sent free to all Alberta secondary schools in March 1989 and contains a Canadian technology case study in each of chemistry, physics and biology.)

Society

Aikenhead, Glen S. (1980). *Science in Social Issues: Implications for Teaching.* Ottawa: Science Council of Canada.
ISBN: 0-662-11183-4
(One of the series of discussion papers prepared for the Science Council of Canada Science Education Study. The entire series is worth reading.)

Aikenhead, Glen S. (1985). Collective Decision Making in the Social Context of Science. *Science Education,* 69(4), 453–475.
CCC: 0036-8326/85/040453-23
(This is an award winning paper from the U of S that is worth reading and rereading.)

Aoki, Ted T. (1979). *Toward Curriculum Inquiry in a New Key.* Edmonton: University of Alberta, Department of Secondary Education.
(The idea of critical reflection can help to describe and guide students' seemingly radical views on STS issues.)

Bronowski, Jacob. (1973). *The Ascent of Man.* London: Little Brown.
ISBN: 0-316-10930-4(H), 0-7088-2035-2(S)
(The video series of the same name is available from ACCESS. The nature of science and the science–society interaction is emphasized.)

Burke, James. (1985). *The Day the Universe Changed.* London: BBC.
ISBN: 0-563-20192-4(H)
(A companion to the BBC video series of the same name, this book examines how the scientific view of the world has affected our view of the world. "Ultimately, the universe is what we say it is.")

Capra, Fritjof. (1982). *The Turning Point.* New York: Bantam.
ISBN: 0-553-01480-3(P)
(Capra presents an argument for a dynamic, multi-perspective (ecological) world view.)

Gaskell, P. James. (1982). Science, Technology and Society: Issues for Science Teachers. *Studies in Science Education,* 9, 33–46.

Institute for the History and Philosophy of Science and Technology, University of Toronto. (1989). *Science in Society: An Annotated Guide to Resources.* Toronto: Wall and Thompson.

Mendelsohn, E. (1976). Values and Science: A Critical Assessment. *The Science Teacher,* 43(1), 20–23.
(An exposition of scientific values for a modern world.)

Polanyi, Michael. (1958). *Personal Knowledge*. London: Routledge and Kegan Paul.

Polanyi, John. (1988). *How Scientific Discoveries Are Made*. A presentation at the annual Alberta Teachers' Association Science Council Conference, Banff, Alberta.

Savan, Beth. (1988). *Science Under Siege: The Myth of Objectivity in Scientific Research*. Toronto: CBC Enterprises.
(Savan's impression of "how science is shaped by the vested interests it serves and by the society that shapes it.")

Snow, C.P. (1961). *Science and Government*. Cambridge MS: Harvard University Press.
(A classic science and society book in which Snow compares the processes and people of science and government and presents the interactions thereof.)

Suzuki, David. (1989). *Inventing the Future: Reflections on Science, Technology and Nature*. Toronto: Stoddart.
ISBN: 0–7737–2354–4

Wall, Byron E. (ed). (1989). *Science in Society: Classical and Contemporary Readings*. Toronto: Wall and Thompson.
(An anthology of readings on the social context of science and technology. Created for the new Ontario academic course, Science in Society.)
ISBN: 0–921332–25–4

STS and Curriculum Emphases

Alberta Education. (1976). *Program of Studies for Senior High School*. Edmonton.

Alberta Education. (1985). *Review of Secondary Programs*. Edmonton.

Alberta Education. (1985). *Secondary Education in Alberta Policy Statement*. Edmonton.

American Association for the Advancement of Science. (1989). *Project 2061: Science for All Americans*. Washington, D.C.
ISBN: 0–87168–341–5
(In the first stage of Project 2061, started in 1985, the goals of science education were re-examined. The second stage involves the design of science curricula.)

Butt, Richard and Eric Mokosch. (1984). *Scientific Enlightenment for a Technological Age*. A Curriculum Proposal for Alberta Secondary Schools. Lethbridge: University of Lethbridge, Faculty of Education.
(Butt and Mokosch provide a "desired image of the future," a description of STS components in a curriculum and then some "policy considerations for the reformation of science education in Alberta.")

Bybee, Rodger W. (ed). (1986). *Science Technology Society: NSTA Yearbook.* Washington DC: National Science Teachers' Association.
ISBN: 0-87355-056-0(P)
(The 1985 NSTA Yearbook features articles by 25 of the STS leaders including G. Aikenhead, R. Bybee, P. Dehart Hurd, J. Soloman and R. Fleming.)

Connelly, Michael F., Robert K. Crocker and Heidi Kass. (1985). *Scientific Education in Canada.* Toronto: Institute for Studies in Education.

Driver, Rosalind and Valerie Oldham. (1986). A Constructivist Approach to Curriculum Development in Science. *Studies in Science Education,* 13, 105–122.
(Driver and Oldham are colleagues at Leeds University, U.K. Oldham did graduate work at U of A.)

Erickson, Gaalen L. (1987). *Constructivist Epistemology and the Professional Development of Teachers.* A paper presented at the annual AAAS meeting, Washington, D.C.
(Erickson is a U of A graduate and now does constructivist research at U.B.C.)

Jenkins, Frank. (1981). *Custom Tailoring the Chemistry Curriculum to the Culture: A Perspective from Canada.* Conference Proceedings: Sixth International Conference on Chemical Education. College Park, Maryland: University of Maryland.

Jenkins, Frank. (1987). *A Taxonomy of Curricular Discourse: A Classification of Science Textbook Discourse.* Unpublished PhD dissertation. Edmonton: University of Alberta.
(Jenkins' research led to the classification of textual statements as science, technology, society, communication and pedagogy statements or as concepts, descriptions, skills and epistemology statements or as resultant knowledge, procedural knowledge and action required statements in a 3-D STS model.)

Mitchell, Ian and John Baird. (1986). *Improving the Quality of Teaching and Learning: An Australian Case Study of the PEEL Project.* Melbourne: Monash University Press.
(PEEL, or Project to Enhance Effective Learning, is a joint project of Monash University and surrounding schools in Melbourne, Australia.)

Peterson, Rita et al. (1984). *Science and Society: A Source Book for Elementary and Junior High School Teachers.* Columbus, OH: Merril.
ISBN: 0–675–20022–9
(This comprehensive teacher textbook contains information on science-related issues, updated science content, classroom activities and methods of teaching science.)

Roberts, Douglas. (1982). Developing the Concept of "Curriculum Emphases" in Science Education. *Science Education,* 66(2), 243–260.
(Roberts introduces the concept of "curriculum emphases" (CEs) and describes seven CEs from science education policy statements. Roberts also makes suggestions as to how CEs may be used in policy, textbook, teacher education and research contexts.)

Science and Technology 11: Curriculum Guide 1986. (1986). British Columbia Curriculum Development Branch.
(Provides teachers with an overview of the 16 modules in the course and outlines the philosophy and rationale behind its inception.)

Science Council of Canada. (1984). *Science for Every Student: Educating Canadians for Tomorrow's World.* Report 36. Ottawa.
ISBN: 0-662-11576-X
(This widely distributed report of the extensive science education study directed by Graham Orpwood and Jean-Pascal Souque is a good starting point for any STS reader.)

Yager, Robert E. (1983). *Curriculum Report.* October, p. 3.

Sample STS Textbooks

ChemCom: Chemistry in the Community by the American Chemical Society. (1988). Dubuque: Kendall/Hunt.
ISBN: 0-8403-4423-6
(A first level chemistry textbook that starts each chapter with an STS issue. Does not employ STS curriculum emphases.)

LoRST: Logical Reasoning in Science and Technology by Glen Aikenhead. (1990). Toronto: Wylie. (In press.)
(LoRST is a Grade 10, academic science module being piloted by Aikenhead in Saskatchewan. Exploring the social issues of alcohol use and abuse in a solid science context, LoRST teaches critical thinking skills, logical reasoning and thoughtful decision making.

SaTiS: Science and Technology in Society by The (British) Association for Science Education. (1986). Herts, England: ASE.
(The SaTiS materials are a series of STS modules to accompany a standard academic chemistry textbook. The modules were primarily written by John Holman—a teacher of A-level chemistry—and are now distributed by the American Chemical Society.)

Science: A Way of Knowing by Glen Aikenhead. (1975). Saskatoon: Department of Curriculum Studies, University of Saskatchewan.

SISCON: Science in a Social Context by Joan Soloman (ed.) for The (British) Association for Science Education. (1983). London: Butterworths.
ISBN: 0-631-91000X (A series).
(Course content emphasizes science, technology and society over pure science.)

STSC Chemistry: Science, Technology, Society, and Communication Chemistry by the Author Group. (1988). Edmonton: Karitann Publishers.
ISBN: 0-921445-30-X
(A two-year academic chemistry textbook that matches science, technology and society curriculum emphases to standard units of study.)

Note: On a continuum of textbooks from those containing the least standard science content to the most, the above examples appear as:

SISCON	LoRST	SaTiS & Text
Science & Technology 11	ChemCom	STSC Chemistry

STS Organizations, Periodicals and Conferences

Alternatives: Perspectives on Society, Technology and Environment
(A Canadian STS magazine for your library.)
ISSN: 0002–6638
Faculty of Environmental Studies
University of Waterloo
Waterloo, ON
N2L 3G1

Bulletin of Science, Technology and Society
102 Materials Laboratory
University Park, PA 16802
U.S.A.

National Association for STS (NASTS)
117 Willard Building
University Park, PA 16802
U.S.A.

National STS Network
117 Willard Building
University Park, PA 16802
U.S.A.

Science•Technology•Society Research Network
(An international organization for science technology education that has a research newsletter and an international conference.)
c/o Dr. Glen Aikenhead
College of Education, Curriculum Studies
University of Saskatchewan
Saskatoon, SK
S7N 0W0

Technological Literacy Conference
(Held in early February in Washington, D.C.)
117 Willard Building
University Park, PA 16802
U.S.A.

Free STS Publications

ChemEcology
Chemical Manufacturers Association
2501 M Street N.W.
Washington, D.C. 20037
U.S.A.

Environment Views
Alberta Environment
9820 – 106 Street
Edmonton, AB
T5K 2J6

Global Education Networks
(A publication of the Alberta Global Education Project.)
11010 – 142 Street
Edmonton, AB
T5N 2R1

STS Reporter
The Pennsylvania State University
117 Willard Building
University Park, PA 16802
U.S.A.

Teachers' Clearinghouse for Science and Society Education
(Collects and reviews materials and publishes a free newsletter three times a year.)
New Walden-Lincoln School
1 West 88 Street
New York, NY 10024
U.S.A.

STS Videos and Films

Each of the STS video and film series has specific programs that may be useful in whole or in part at particular stages of the secondary science curriculum.

A Planet for the Taking with David Suzuki is a CBC series that considers the arrogance and self-centredness of the human species on our planet. The series also focuses on the beneficial uses and unfortunate misuses of science and technology in human history.

Connections with James Burke is a BBC series about the connections between various significant technologies and the effects of technology on society. (ACCESS.)

Science Perspectives by the National Film Board is a 1989 release that presents a chemistry, a physics and a biology STS issue from a science, a technology and a society perspective. The video is interactive and uses new techniques to allow you to search for different parts of the video. (NFB.)

The Ascent of Man with Jacob Bronowski is a BBC series on the intellectual interaction of science and society. (ACCESS.)

The Day the Universe Changed with James Burke is a BBC series that explores how scientific concepts over the centuries changed the way we see the world. (ACCESS.)

The Renewable Society is an ACCESS series that considers the questions concerning renewable vs. nonrenewable energy and resources. (ACCESS.)

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